ELECTRICITY

ONE HUNDRED YEARS AGO AND TO-DAY.

With Copious Notes and Extracts.

BY

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TO

JAMES HAMBLETT,

PRESIDENT OF THE DEPARTMENT OF ELECTRICITY,
BROOKLYN INSTITUTE OF ARTS AND SCIENCES,
THIS LITTLE BOOK IS RESPECTFULLY
DEDICATED BY THE AUTHOR.

PHILADELPHIA, May, 1894.

PREFACE.

This little book, "Electricity, One Hundred Years Ago and To-day," contains the text of a lecture delivered before the Electrical Section of the Brooklyn Institute. In preparing the lecture for publication, which I have determined to do in the belief that it may be of value to students of Electricity, I have concluded to permit the text to remain substantially as delivered, preferring to add, in the way of foot-notes, whatever additional matter may be required, rather than to materially change the original matter or arrangement.

The wide scope of the lecture, which embraces the progress made by electric science practically from its birth to the present day, necessitated, from the limit of time of a single lecture, a much briefer treatment of many important discussions and inventions than seemed advisable when the lecture was put in book form. Various portions of the original lecture, have, therefore, been considerably extended by means of foot-notes.

In tracing the effects produced by great discoveries or inventions, it has been deemed desirable to introduce copious extracts from the papers in which such discoveries or inventions were originally described. In this manner only, can an intelligent conception be formed of the importance of a discovery, or the completeness of an invention.

In some cases no little difficulty has been experienced in finding the exact publication in which the first description of a great discovery or invention was given. This, of course, is almost necessarily the case when the discovery or invention belongs to the type for which a number of rival claimants exist. A difficulty in such studies, arises, too, in readily attaining access to a sufficiently complete collection of works on the early literature of the science. I have been fortunate, in this respect, to have had at my disposal the very excellent library of the Franklin Institute, in which is to be found, perhaps, the most complete collection of the Transactions and Proceedings of learned societies, and of the general and periodical scientific literature of the last century or so, that is to be found in this country.

It will of course be understood, that no pretense is made in this little book, of doing any more than treating, in the most general manner, some of the more interesting facts concerning those great discoveries and inventions that may fairly be considered as creating epochs in the history of electrical progress. Many volumes would necessarily be required to give each of such discoveries or inventions the treatment its importance would require.

In common with many others I have always, hitherto, ascribed to Sir Humphrey Davy the honor of having first discovered the carbon voltaic arc. In endeavoring to find the original publication in which this discovery is described, I found that Davy was anticipated in the discovery by many others, the introduction of whose names, together with the details that would be necessary in tracing the progress of so important a discovery, would require a much greater space than I have at my command in this little book.

The experiment most generally referred to at present and, indeed, in literature contemporaneous with the time of Davy, as being the first ever made with the carbon voltaic arc, was that made by Davy with a voltaic pile or battery of some two thousand couples belonging to the Royal Society of London. These experiments, however, differed only in degree, and not in character, from those performed by many others before the date of Davy's public experiments, and were merely the first in which the full splendors of the voltaic light were publicly demonstrated.

The extracts from early writers have been made comparatively full, becanse of the difficulty most students experience in gaining access to the books or periodicals in which such publications first appeared. The extracts from publications concerning the more recent discoveries or inventions are less frequent, because such are either more generally known or more readily accessible.

The plates from which the pages of this book are printed came into possession of the present publishers through the failure of the firm which had originally undertaken the publication of the work. As the typographical execution falls short of the standard of the publishers with whose imprint it is now issued, it is but fair to relieve them, by this explanation, of responsibility for any typographical deficiencies that may be observed.

EDWIN J. HOUSTON.

Philadelphia, Central High School,
May, 1894.

ELECTRICITY,

ONE HUNDRED YEARS AGO AND TO-DAY.

KING SOLOMON speaking of his age, said, "There is nothing new under the sun," and King Solomon was qualified to judge, for he was learned far beyond any man of his time, and, possibly, beyond any man who came after him.

There is a type of man who is apt to echo Solomon's judgment; not only, perchance, because he wishes this judgment to be true, but also because it is a very rare case in which he cannot find facts sufficient to show reasonable grounds for such judgment. I allude to the scientific expert, whose zeal for his client, sometimes leads him to force facts, or to interpret by-gone records in the light of the knowledge of to-day.

The much maligned expert, however, provided he adheres to facts, is as much justified in presenting the best case possible for his client as the lawyer, the clergyman, or any other special pleader.

To the superficial student of scientific progress, it may readily appear as if, in reality, there was nothing new under the sun; that everything that is, has been. Let any student, however, once drink deeply at the fountain of scientific historical knowledge, and he will view the facts in a very different light.

To assert that there is nothing new under the sun since the time of Solomon is to assert that the human mind has made no progress during that time; has undergone no development. Certainly no one can be found willing to make such a monstrous assertion.

Our minds are cast after a common pattern, in substantially the same mould. While in particular cases, we must necessarily admit the existence of finer texture, of better hereditary peculiarities, of higher development, and of grander possibilities, yet, after all, thoughts conceived by one mind are apt to be common to many, if not to the majority of minds.

At certain times in the world's progress the environment may cause so rapid a development of the germs of great ideas, the incentive to unusual effort may be so great, the necessity for a new combination of ideas so urgent, and the encouragement of an age ripe for the birth of such ideas, so marked, that substantially the same ideas may be conceived simultaneously in different parts of the world.

At other times the peculiarities of the environment may be so unfavorable, the incentive to unusual effort so small, the necessity for new ideas so apparently limited, and the encouragement so feeble, that although the idea may be born, yet it may fail to meet with recognition by the world, and so be passed by and forgotten, only, in some later, riper time to be again independently conceived and offered to the world.

Ideas born out of time, like immature or unripe fruit, die an untimely death. A great idea is conceived in different parts of the world, by different brains, at times, often hundreds of years apart. The first producer of the idea is unnoticed, perhaps ridiculed, possibly persecuted, and the gift, freely offered to the world, is consigned to oblivion until some historian of science again brings it to light; while a later originator of the same idea is hailed by an applauding world, because such world has developed so far as to be able to appreciate the idea, and is in need of it; and yet the earlier propounder was probably intellectually greater than the later.

Great ideas or inventions may be arranged under three types or classes, viz.,—

(1). Immature or incomplete.

(2). Untimely and therefore unfruitful.

(3). Fruitful because mature and timely.

Immature or incomplete ideas or inventions produce but little influence on the world—at times, however, they are of great value because they tend to direct thought to certain channels and thus act as forerunners of greater and more valuable ideas.

Untimely ideas may be mature, but the times are unripe for them; the condition of the environment unsuited; and, therefore, though mature and complete in themselves, yet like unripe fruit they are unfruitful and produce no progeny for the development of the world. As a rule, the originators of such ideas or inventions belong to that limited class of men who are so far beyond their fellows, that the world is unable to understand them.

Originators or inventors of this type of ideas are not apt to have contestants for priority of invention or origination. Their thoughts or inventions are apt to stand alone. They give their thoughts or inventions to an unready world, that fails to appreciate such thoughts or inventions, and immediately forgets them and relegates them to oblivion.

Ideas or inventions, which are fruitful because mature and timely, are of far greater value to the world than those of the second type since they bear fruit almost immediately. It matters little to the world whether they have been conceived before or not. When practicable, they almost necessarily find extended application because the times are ripe for them.

The fact that such ideas are frequently found to be old does not prevent them from being original with their later producers. The latter, however, cannot claim to be the first originators of great ideas, nor can they justly claim a position in the class of the favored few who stand alone.

Ideas or inventions of the third type almost necessarily belong to a class and not to a favored few.

Concerning the second type of ideas or inventions, there sometimes arises, though unfortunately for the world's progress very seldom, inventors whose genius is so great that although their ideas are born out of time, yet they are presented in such a matured form and so intelligently and completely worked out in that most valuable state of actual operation, that the world is forced, despite its indifference, to receive and employ them. Such geniuses, by their unusual abilities, get in advance of the world of thought and action and drag it up to their position of vantage.

As to the third type of ideas or inventions, it almost invariably happens, when the world is ripe and waiting, that they are simultaneously made by different minds in different parts of the world, and it is this fact that has led the superficial to accept the belief expressed by Solomon of old.

Prof. Youmans expresses a similar idea.* In his opinion, great ideas belong to eras rather than to individuals.

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* The work of Prof. E. L. Youmans, above referred to, is "The Correlation and Conservation of Forces: A Series of Expositions by Prof. Grove, Prof. Helmholtz, Dr. Mayer, Dr. Faraday, Prof. Liebig and Dr. Carpenter." New York: D. Appleton and Company, 1883. On page XV. of the introduction, Prof. Youmans says,—

"In the history of human affairs there is a growing concep-

As the advance wave of intellectual progress moves towards the boundaries of the unknown, several investigators moving with that wave must, at very nearly the same time, discover new features and facts on the horizon beyond. At some times they see these from the same point of view, and more or less complete inventions simultaneously result. At other times several observers see an object from different points of view, and those partial and conflicting descriptions are given which lead to that inevitable scientific controversy which tends to renewed observation and more accurate description.

The scientific historian who follows the advance of electrical progress and endeavors to note the positions

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tion of the action of general causes in the production of events, and a corresponding conviction that the part played by individuals has been much exaggerated, and is far less controlling and permanent than has been hitherto supposed. So also in the history of science it is now acknowledged that the progress of discovery is much more independent of the labors of particular persons than has been formerly admitted. Great discoveries belong not so much to individuals as to humanity ; they are less inspirations of genius than births of eras. As there has been a definite intellectual progress, thought has necessarily been limited to the subjects successively reached. Many minds have been thus occupied at the same time with similar ideas, and hence the simultaneous discoveries of independent inquirers, of which the history of science is so full. Thus at the close of the sixteenth century, philosophers had entered upon the investigation of the laws of motion, and accordingly we find Galileo, Benediti, and Piccolomini proving independently that all bodies fall to the earth with equal velocity, whatever their size or weight. A century after, when science had advanced to the attained by it at different eras, during the past one hundred years or so, will unquestionably find much that is of interest, much that is perplexing, but nothing devoid of instruction.

Let us then, with this historian, pass hurriedly over the path of the wave of electric progress and note the more important records left by it at different stages of its advance; and, as we study its more important records, let us compare them with corresponding points in electrical progress during the present time, so as to assure ourselves whether such progress has been real or is only apparent.

Following the three divisions of great ideas already referred to, viz., the immature, the untimely and the

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systematic application of the higher mathematics to general physics, Newton and Leibnitz discovered independently the differential calculus. A hundred years later questions of molecular physics and chemistry were reached, and oxygen was discovered simultaneously by Priestley and Scheele, and the composition of water by Cavendish and Watt. These discoveries were made because the periods were ripe for them, and we cannot doubt that if those who made them had never lived, the labors of others would have speedily attained the same results. The discoverer is, therefore, in a great degree, but the mouthpiece of his time. Some discern clearly what is dimly shadowed forth to many; some work out the results more completely than others, and some seize the coming thought so long before it is developed in the general consciousness, that their announcements are unappreciated and unheeded. This view by no means robs the discoverer of his honors, but it enables us to place them upon a juster estimate, and to pass a more enlightened judgment upon the rival claims which are constantly arising in the history of science."

fruitful, let us start at the point of genesis of electric progress and examine that oft-reverted-to experiment of the Greek Thales.*

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*Thales occupies so prominent a place in the present world of electrical science, and so little is generally known of his attainments in other directions, that I have thought it well to quote a brief account of his life as given by Benj. Martin in a publication entitled "Biographia Philosophica." Being an account of the Lives, Writings, and Inventions, of the most eminent Philosophers and Mathematicians who have flourished from the Earliest Ages of the World to the present Time. By Benjamin Martin, London: Printed and sold by W. Owen, near *Temple-Bar*, and by the Author, at his House in *Fleet-street.* 1764. Page 1.

"Thales was born, as the best Writers agree, in some Part of the 35th Olympiad, flourished in the 50th, and died about the 58th; the Interval between his Birth and public Appearance in *Greece*, was passed in Study, and Travels in various Parts of *Asia*, and into *Ægypt*; in the former he acquired his first Insight into *Astronomy*, and, in the latter, his first Acquaintance with *Geometry*, *Mystical Divinity*, and *Natural Knowledge*. Having finished his Studies abroad, he returned to his Native City, *Miletus*, and transported the Stock of Learning he had acquired into his own Country."

"There are not any particular Circumstances mentioned in his History respecting significant Occurencies in his Travels, other than the Favour he met with from *Amasis* King of *Ægypt*, which Favour he lost by being too free in his Opinions concerning Kings: was, by such Freedom, obliged to leave the Country; which was the probable Cause of his returning, at that Time, to *Miletus*."

"In *Miletus* he lived for some Time as private as possible, devoted to Study and Contemplation, and in instructing some few in the Learning he had acquired. These were *Anaximander* and

It was not much, when viewed in the light of the world at its birth, some 600 B. C.; merely a piece of amber rubbed against the clothing; merely the gaining of a strange property of first attracting and then repelling light objects brought near it.

It was, however, the birth of a great idea, an idea

Anaximines, both Natives of *Miletus*; and afterwards *Pythagoras*, of what Country unknown, but usually called of *Samos*, so famed, as the Constitutor of the *Italic Sect*, and who assiduously pursued his Master's Steps, both in his Studies, and in his Travels."

"*Thales*, in this his Retirement, was courted by many, but cautiously avoided either attending, or receiving any Favours from them. He was often visited by *Solon*, and is said to have taken great Pleasure in the Conversation of *Thrasybulus*, whose excellent Wit caused our Philosopher to forget that he was Tyrant of *Miletus*."

"There flourished, at the same Time with him, six others, distinguished by their singular Wisdom by their Morals, Rules, and Practice; but the Epithet of *Wise* was given to *Thales* for his speculative Learning."

"*Laertius*, and with him various other Writers, agree, that he was the Father of the *Greek* Philosophy, the first that made any Researches into natural Knowledge, or Enquiry into Mathematics."

"His Doctrine was, that Water, Moisture, or Humidity is the first Principle of natural Bodies, whereof they consist, and whereinto they resolve; and that *God* is the Mind, which formed all Things of Water."

"Of the World, he taught, there was but one, and that made by God; that it is disposed in due and regular Order, and that God animates the whole."

"In *Geometry* he is said to have been an Inventor, as well as an Improver; a Science that had its Birth by Necessity in *Ægypt*, where *Thales* acquired his primary Instruction, as Commerce first gave Being, by the like Necessity, to *Numbers*."

"He gave the first Light into the Knowledge of scalenous, and that unfortunately, for the world's progress, belonged to the class of immature ideas. Viewed in the light of to-day, its importance can hardly be over-estimated. It pointed out a *terra incognita;* an unknown realm of phenomena that occupied nearly the entire domain of nature, and only waited patiently to be observed. It was

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other Triangles, many of which *Euclid*, has digested into his *Elements;* but that for which he is more particularly celebrated, as being, according to *Laertius*, his Invention, is what now appears as the 47th Proposition of *Euclid*, *That the Sums of the Squares of the two lesser Sides of a right angled Triangle is equal to the Square of the greater Side;* which is, however, disputed as the Invention of his Disciple *Pythagoras*. But all the Writers agree, that he was the first, even in *Ægypt*, who took the Height of the Pyramids by the Shadow, in the Manner the same is now usually effected, and therefore needs not any Illustration."

"As an *Astronomer*, he divided the celestial Sphere into five Circles, or Zones, the *Arctic*, the *Summer Tropic*, the *Equator*, the *Winter Tropic*, and the *Antartic Circle*, placing the *Zodiac* under the three middle Circles, touching them all as it passes, and each of them cut in right Angles by the Meridian, that extendeth from Pole to Pole; Which have unjustly been ascribed to more modern Discoveries."

"He first observed the apparent Diameter of the Sun, which he concluded to be the 720th part of the Circle or Zodiac, which he appears annually to describe about the Earth, which is divided into 360 Degrees; and first discovered the Constellation of the lesser Bear."

"He likewise first observed the Nature and Course of *Eclipses*, and calculated them to an Exactness; one in particular, about the 50th Olympiad, memorably recorded by *Herodotus*, as it happened on a Day of Battle between the *Medes*, and *Lydians*, which, *Laertes* says, he had foretold to the *Ionians*. And the same Author informs us that he divided the Year into 365 Days; but this Division he seems to have had from the *Ægyptians*. *Plutarch de placit. Philos*, not only confirms his general Knowllike the sailing of Columbus on that eventful voyage which resulted in the discovery of the Continent of the Future.

But the idea was incomplete, the world was either skeptical or unable to understand the true significance of the phenomenon, or to appreciate the vast treasures

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edge of Eclipses, but that his Doctrine was, that an Eclipse of the Sun is occasioned by the Intervention of the Moon, as may be seen in a Bason of Water, or Looking-glass; and that an eclipse of the Moon is caused by the Intervention of the Earth."

"The Writers of his Life agree, that he was addicted to judicial Astrology; and *Tully* thinks there is something in that Science, and of his Acquaintance there-with, which he aims to confirm by the following Story:"

"That *Thales* being upbraided for his Poverty, resulting from the Study of Science, and foreseeing by his Skill in Astrology, there would be a Plenty of Olives that Year, he purchased all the Gardens about *Miletus* and *Chios*, and thus having acquired a Monopoly, disposed of them again at high Prices, and then told his Neighbours, that it was very easy for Men of Learning to be rich if they chose it, but that Wealth was not their Aim."

"*Laertius*, and some others, agree with *Tully* in his Notion of this being an Astrological Prediction, which is far from being a clear Point: It is sufficient, that he was capable of making a good Judgment of the approaching Season, and that it would be such a Season, as wherein Olives are usually most plentiful. This, however, sufficiently evinces, that he had more worldly Wit than his Neighbours conceived, when he thought proper to employ it; as is the Case of most Studious Men, when they turn their Attention that Way, and affect the Object, as by Study they acquire a Sagacity and Penetration not common to the In-attentive: But, as Self-interest is the ruling Passion of our Natures, Men turned only to the Attainment of Wealth, will, with some Reason, smile at those who reduce themselves to Poverty, in order to make others learned."

of knowledge it was ready to unlock. Now that a riper world has availed itself of this first experiment in elec-

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"It is a sufficient Illustration of the Wisdom of *Thales*, that he was the Inventor, or Improver, in many Branches of useful Knowledge; and whether right or wrong in his Contempt of Wealth, his Sagacity in other Respects superior to most Men."

"His *Morals* were as just, as his *Mathematics* well grounded, and his Judgment in civil Affairs equal to either; so that his Knowledge was as general, as the Good of Mankind his Care; and as we have given a brief account of his Skill in Science, it may not be amiss to give here a concise Taste of his Morals, summed up in a few Lines."

"Fear e'er thou sin, thyself, tho' none be nigh,
Life fades, a glorious Death can never die;
Let not thy Tongue discover thy Intent,
'Tis Misery to dread, and not prevent.
He helps his Foes that justly reprehends;
He that unjustly praiseth, harms his Friends;
That 's not enough, that to Excess extends."

"He was very averse to Tyranny, and esteemed Monarchy little better in any Shape; he was used to say, That a Tyrant, who chuseth rather to command Slaves than Freemen, is like an Husbandman who preferreth the gathering of Locusts and catching Fowls, to the reaping of Corn."

"Concerning his Writings, it remains doubtful whether he left any behind him. *Augustine* mentions some Books of *Natural Philosophy; Simplicius*, some written on *Nautic Astrology; Laertius*, two Treatises on the *Tropics* and *Equinoxes;* and *Suidas*, a Treatise on *Meteors*, written in Verse."

"His Death happened in Point of Time as is said above;the Occasion appears to have been his attending the *Olympic* Games, where, opprest with Heat, Thirst, and the Weakness of his Years, he, in public View, sunk into the Arms of his Friends."

"He was buried, according to his own Appointment, in an obscure part of the *Milesian* Fields, where he predicted in future Times their *Forum* should be."

tricity, it seems to have been a very easy thing to unfold one general principle in electric science after another, but, like the problem of Columbus as how to balance an egg on one end, it was quite simple only after it was once done, and the way pointed out.

Thales' original experiment bore no fruit until several thousand years had passed. It is true that Theophrastus* some three hundred years after the time of Thales showed that some species of tourmaline when

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It is a significant fact that the Historian of Thales, writing as he did in 1764, left out in the various accounts he gave of the life work of this remarkable man, that particular observation concerning the properties acquired by rubbed amber, which in our own day has again brought Thales' name so frequently into the records of electrical investigations.

*Theophrastus flourished about 300 years before Christ. In his work on precious stones he asserts that amber possesses the same property of attracting light bodies that lyncurium does, which, he says, "Attracts not only straws and small pieces of sticks, but even thin pieces of copper and iron."

The lyncurium here referred to is believed to be a variety of tourmaline, since all the properties described by Theophrastus as being possessed by it are possessed by tourmaline. For example, that lyncurium was used for seals, was pellucid, was of a deep red color, required no small labor to polish and was endowed by friction with an attracting power like amber.

rubbed, acquired similar properties to amber but the world was still unappreciative, and again allowed golden opportunity to pass by.

It seems strange from our standpoint of to-day, that the existence of the electric force could have remained for so long a time unrecognized. It was certainly not for the want of acute minds. The Egyptians, the Greeks, or the Romans were in many respects as intellectually developed as any of the earth's present cultured races. The road leading into the unknown domain of electric science was pointed out to them, but this road was neglected and soon forgotten, and, only during the past one hundred years or so, became the great thoroughfare of scientific progress.

In thinking over the lapse of time during which the electric force remained unnoticed, though the way was pointed out, the probability has often occurred to me that in our own time the world is on the eve of the great discovery of some new and hitherto unrecognized force connected with the phenomena of thought or mental activity. It may be that the unprecedentedly rapid advance made by the wave of scientific progress is hurrying us nearer and nearer to the recognition of this force and of other forces that are undreamt of in our modern philosophy.

Too often is the cry "*cui bono*" raised when some apparently trifling physical phenomenon is first recorded. Because its place among other natural phenomena has not yet been clearly pointed out, it is too apt to be regarded as insignificant. I do not doubt but that those friends and acquaintances of Thales, to whom he first showed his great experiment, regarded him in the light of a harmless enthusiast, or, possibly, attributed approaching senility to one willing to indulge in such childish experiments; and yet, the utility of the experiment was probably as great, if not greater, than that of any subsequent experiment ever tried in the wide domain of physical science.

Examining Thales' original experiment in the light of to-day, we should carefully avoid forming the following hasty conclusions:—

(1). That all the forces of nature have been discovered.

(2). That any correctly recorded natural phenomenon though apparently trivial is of no value to the world.

I do not purpose, however, tracing the progress of electricity from the time of Thales until now. That would require much more time than is placed at my disposal to-night. We are now interested in discussing the knowledge possessed by the world as regards electricity about one hundred years ago, and in comparing and contrasting it with our present knowledge. I say about one hundred years ago, as I do not wish to hamper our investigations by rigid limits.

For nearly two thousand years this great discovery was permitted to slumber, and it was not until towards the close of the sixteenth century that Dr. Gilbert, physician to Queen Elizabeth, extended the observation of Theophrastus and showed that many bodies besides amber and tourmaline, when subjected to friction, acquire the strange property of first attracting and then repelling light bodies brought near them.

Gilbert published his observations in the year 1600, in a book called "*De Magnete.*"* He divided bodies into two great classes, electrics or those which could be

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*Dr. Joseph Priestley, in a work published in two volumes in London, in 1775, entitled,—"The History and Present State of Electricity, with Original Experiments," in alluding to the fact that Gilbert greatly extended the list of substances that could be electrified by friction says, on page 2, of Vol. I,

"The attractive nature of amber is occasionally mentioned by Pliny, and other later naturalists; particularly by Gaffendus, Kenelm Digby, and Sir Thomas Brown; but excepting the electricity of the substance called *jet* the discovery of which was very late (though I have not been able to find its author) no advances were made in electricity till the subject was undertaken by William Gilbert, a native of Colchester, and a physician at London; who, in his excellent Latin treatise *de magnete*, published in the year 1600, relates a great variety of electrical experiments. Considering the time in which this author wrote, and how little was known of the subject before him, His discoveries may be justly deemed considerable, though they appear trifling when compared with those which have been made since his time."

"To him we owe a great augmentation of the list of electric bodies, as also of the bodies on which electrics can act; and he has carefully noted several capital circumstances relating to the electrified by friction, and non-electrics or those which could not be so electrified. Gilbert's classification is now known to be based on an erroneous idea, since bodies like the metals, which conduct electricity, are as readily electrified by friction as are non-conductors like glass or resin. If conductors be held in the hand, as Gilbert held them when endeavoring to evoke the electric force by friction, they will at once necessarily lose their electric charge by discharge through the body of the experimenter to the earth. If, however, they be

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manner of their action, though his theory of electricity was very imperfect, as might be expected."

"AMBER and jet were, as I observed before, the only substances which, before the time of Gilbert, were known to have the property of attracting light bodies when rubbed; but he found the same property in the *diamond, sapphire, carbuncle, iris, amethyst, opal, vincentina, Bristol stone, beryl, and crystal.* He also observes that *glass*, especially that which is clear and transparent, has the same property; likewise all *factitious gems*, made of glass or crystal; *glass of antimony*, most *sparry substances*, and *belemnites.* Lastly, he concludes his catalogue of electric substances with *sulphur, mastic, sealing wax* made of gum lac tinged with various colours, *hard rosin, sal gem, talc,* and *roche alum.* Rosin, he said, possessed this property but in a small degree, and the three last mentioned substances, only when the air was clear and free from moisture."

"ALL these substances, he observes, attracted not only straws, but all metals, all kinds of wood, stones, earth, water, oil; in short, whatever is solid, and the object of our senses. But he imagined that air, flame, bodies ignited, and all matter which was extremely rare was not subject to this attraction. Gross smoke, he found, was attracted very sensibly, but that which was attentuated very little."

insulated in any suitable manner, they are, as we all know, as readily electrified by friction as any other bodies.

It may be interesting to inquire what mental qualifications Gilbert possessed which permitted him to be practically the first man after a lapse of some two thousand years to extend Thales' original observation. I think the answer is evident. The reason is to be found not so much in the higher mental development of Gilbert, although he was unquestionably possessed of a very remarkable intellect, but is to be found rather in his methods.

Gilbert, who was born in 1540, flourished about the same time as Bacon, who was born in 1561. Before the time of Bacon, as you are probably aware, the inductive method of studying natural phenomena was almost unknown. The early observers, especially those belonging to the school of Greece, instead of endeavoring to ascertain the causes of natural phenomena by questioning nature through experiments, and reasoning out natural causes from the results of such experiments, assigned for the phenomena fanciful causes and reasons which necessarily obscured the truth. *Bacon taught a

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* In an introduction to an "Account of Lord Bacon's Novum Organon Scientiarum," published in London in 1827, in a serial publication entitled the "Library of Useful Knowledge," the following brief outline of Bacon's system of philosophy is given on page 8;

system of Philosophy called Inductive Philosophy, in which the causes of phenomena are determined by careful experimentation and the facts obtained from one set of series of experiments used as the basis of subsequent experiments. (See note on p. 24.)

"It was reserved, however, for Francis Bacon, Lord Verulam, to break the spell of the mighty enchanter of Stagira, and to give a final blow to the scholastic philosophy;—to make one grand and general attempt to deliver men's minds from the bondage of two thousand years;—to assert the right of that reason with which the beneficent Creator has endowed man, as above all authority merely human;—and to sketch the outlines of one grand and comprehensive plan, that should include in it the endless varieties of our knowledge, and guide our inquiries in every branch. Born in the year 1561, and early entered as a student at Trinity College, Cambridge, this great genius soon began to feel dissatisfied with the vagueness and uncertainty of the existing state of knowledge, the want of connexion between the sciences and the arts, and the consequent uselessness of the reigning speculations as regarded the purposes of life. The more he thought on the subject, the more he was convinced of the vanity of the scholastic learning of the times, and of the necessity of a thorough reformation in the method of treating the knowledge of nature, by laying aside all conclusions not founded on observation and experiment. He saw plainly that a great part of the evil lay in the extensive influence which Aristotle still possessed in the schools; that *nature* and *fact* were neglected for the study of his doctrines, which were the arbiters in all disputes; the properties of matter, and the laws of motion, by which all effects are produced, were lost in useless distinctions and dry definitions; the powers of the mind were exhausted in grave trifling and solemn folly; and the real advancement of human knowledge was altogether hopeless, so long as such a state of things prevailed. A century or two earlier, the contests about *names*, and *forms*, and *essences*, were sometimes more serious than a mere strife of tongues; they ended in actual bloodshed; while the desputants

Passing over a considerable lapse of years from the time of Gilbert, I would briefly call your attention to

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took the side either of *Occam*, "*the most subtil*," or *Duns Scotus* "*the invincible*," the famous champions of the day ; and if the din of this philosopical, or rather *un*philosopical war now raged no longer,—if those imposing titles were not now heard which had formerly been bestowed on the leader of rival parties, such as the *most profound*, the *marvellous*, the *perspicuous*, the *irrefragable*, the *most resolute*, the *angelical*, the *seraphic Doctor*,—it was that all inquiry had well nigh ceased, and the minds of men were cast, with a very few exceptions, into a profound slumber, and filled only with the romantic visions of an imaginary philosophy.—Such had been the state of things at the time of Lord Bacon, and the brief notice we have taken of it may serve to throw light on the real value of his labours, which had for their object the establishment of a philosophy that is in fact no other than the philosophy of reason and common sense, in opposition to all mere theory and fancy, and to all impositions."

"Under these circumstances Bacon wrote his Organon. His qualification for this bold attempt to clear the barren wastes of science, and to sow the seeds of a new creation of useful knowledge, will be best seen by studying his doctrines. We shall, therefore, now proceed to give an account of this most important and considerable part of his general work, the *Instauratio Magna*, or *Instauration of the Sciences.* Its title was probably suggested by Aristotle's *Organon*, containing his Logic ; it is called *Novum Organon Scientiarum*, or *a New Method of Studying the Sciences*, from the Greek word *organon*, which signifies an *instrument* or *machine*. The grand principle which characterizes this great work, and by the proper use of which its author proposes the advancement of all kinds of knowledge, is the principle of *Induction*, which means, literally, *a bringing in* ; for the plan it unfolds is that of investigating nature, and inquiring after truth, not by reasoning upon mere conjectures about nature's laws and properties, as philosophers had been too much accustomed to do before, but by *bringing together*, carefully and patiently, a variety of particular facts and instances ; viewing these in all possible

Stephen Grey,* who, in 1729, first pointed out the distinction between conductors and non-conductors of electricity.

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lights ; and drawing, from a comparison of the whole, some general principle or truth that applies to all. The foundation of this philosophy lies, in short, in the *history of nature itself*—in making a laborious collection of the facts relating to any one subject of inquiry, previously to any attempt at forming a system or theory. Actual experiment, which Bacon significantly terms "asking questions of nature," must be resorted to, where experiments, as in chemistry, can be made ; observations must be accurately collected, in the subjects proper to these, as astronomy ; and conclusions are, in all cases, to be drawn only from what is actually witnessed, after the comparison of a sufficient number of facts, and a due regard to objections. In his treatment of this important subject of Induction, a new and more rational employment of the faculties is exhibited than the world had ever seen ; and never before was there laid down to the minds of men the true theory of investigating all truth, whether natural or moral ; indeed, Bacon has well merited the appellation he has received—the *Prophet of the Arts*, and the *Father of Experimental Philosophy*."

Proceeding on so sound a basis as this, an investigator, possessed of the powerful intellect of Gilbert, was necessarily soon far advanced into this hitherto undiscovered domain of science. I will not ask you to follow me in his many researches, but will refer you for a fuller description of the same to his work "De Magnete," already referred to. See note in Appendix.

* In Dr. Joseph Priestley's work on the "History and Present State of Electricity," already referred to, thus describes on page 32, of Vol. I., the labors of Stephen Grey in the domain of electricity.

"AFTER this long interval, commences a new æra in the history

The fact now so well known to us of the enormous rapidity with which electrical effects, produced at one end of a line wire or conductor, are manifested at the other end, which may be hundreds or even thousands of miles distant, naturally excited considerable wonder at the time it was first discovered, and it is not at all

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of electricity; in which we shall have the works of another labourer in this new field of philosophy to contemplate, viz., Mr. Stephen Grey, a pensioner at the Charter House. No person who ever applied to this study was more assiduous in making experiments, or had his heart more entirely in the work. This will appear by the prodigious number of experiments he made, and some considerable discoveries with which his perseverance was crowned; as well as by the self-deceptions, to which his passionate fondness for new discoveries exposed him."

At this time Grey had conducted numerous experiments on the conducting powers of different substances, and had succeeded in passing an electric discharge downwards through a suspended pack thread. He also experimented on the ability of hempen threads horizontally supported to carry discharges. In order to support these lines he suspended them by means of fine silken threads which he believed prevented the electricity from escaping because they were thin. He afterwards discovered that this action depended on their non-conducting power for the discharge rather than on their small diameter. His remarks concerning these results we find on page 40 of Priestley's work above quoted.

"In the same manner in which *silk* was found to be a non-conductor, it is probable that, about the same time, *hair*, *rosin*, *glass*, and perhaps some other electric substances, were found to have the same property, though the discovery be no where surprising, that even at this very early date, some hints were thrown out as to means whereby the electric force could be utilized for the purposes of telegraphic communication. Such suggestions we find made by numerous writers and, indeed, some actually tried the experiment. Among these I may mention Watson,* who, in 1747

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particularly mentioned: for we shall presently find Mr. Grey making use of them to insulate the bodies which he electrified."

"AFTER this, Mr. Grey and his friend amused themselves with trying how *large* surfaces might be impregnated with the electric effluvia; electrifying a large map, table cloth, &c. They also carried the electric virtue several ways at the same time, and to a considerable distance each way."

"THE magnetic effluvia, they found, did not in the least interfere with the electric; for when they had electrified the load stone, with a key hanging to it, they both attracted leaf brass like other substances."

* "William Watson in a communication to the Royal Society of London in 1747, refers to the ability of electricity to pass through circuits or lines of substances *non-electrical* in character. By non-electrical circuits Watson referred to substances like conductors which could not (as he thought) be electrified by friction. In Vol. X. of the Abridged Philosophical Transactions, on page 347, he says:

"In the paper I did myself the honour some time ago to communicate to the *Royal Society*, I took notice, that, among the many surprising properties of Electricity, none was more remarkable, than that the electrical power, accumulated in any non-electric matter contained in a glass phial, described upon it's explosion a circuit through any line of substances non-electrical in a considerable degree; if one end thereof was in contact with the external surface of this phial, and the other end upon the explosion touched either the electrified gun-barrel, to which erected various conducting lines which extended for distances of several miles and used the earth as a return. In sending electricity through these lines Wat-

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the phial in charging was usually connected, or the iron hook always fitted therein. This circuit, where the non-electric substances, which happen to be between the outside of the phial and it's hook, conduct Electricity equally well, is always described in the shortest manner possible; but if they conduct differently, this circuit is always formed through the best conductor, how great soever it's length is, rather than through one which conducts not so well, though of much less extent."

"It has been found, that in proportion as bodies are susceptible of having Electricity excited in them by friction, in that proportion they are less fit to conduct it to other bodies; in consequence whereof, of all the substances we are acquainted with, metals conduct best the electrical powers; for which reason the circuit before spoken of is formed through them the most readily. Water likewise is an admirable conductor; for the electrical power makes no difference between solids and fluids as such, but only as they are non-electric matter."

The electrified gun-barrel referred to was connected to the electrical machine and was provided with an iron hook on which was hung a Leyden phial. Under these circumstances, it will be seen that the Leyden phial was discharged through the conducting circuit.

On page 357, of the publication above referred to, Watson describes an experiment made concerning the passage of an electrical discharge through a conducting path as follows:—

"The electrifying machine being placed up one pair of the stairs in the house at *Highbury-barn*, a wire from the coated phial was conducted upon dry sticks as before, to that station by the side of the *New River*, which was to the northward of the house. The length of this wire was 3 furlongs and 6 chains, or 2376 feet. Another wire fastened to the iron bar, with which, in making the son employed the discharge of a Leyden phial which had then been two years invented. In order to determine whether or not the electric shocks had been trans-

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explosion, the gun-barrel was touched, was conducted in like manner to the station upon the *New River* to the southward of the house. The length of this wire was 4 furlongs 5 chains and 2 poles, or 3003 feet The length of both wires, exclusive of their turnings round the sticks, was 1 mile, 1 chain, and 2 poles, or 5379 feet. For the more conveniently describing the experiments made here, we will call the station to the northward D, and the other E.

At this distance the gentlemen proposed to try, first, whether or no the electrical commotion was perceptible, if both the observers at D and E, supported by originally-electrics, touched the conducting wire with one hand, and the water of the *New River* with an iron rod held in the other ? Secondly, whether or no that commotion was perceptible, if the observer at E, being in all respects as before, the observer at D, standing upon wax, took his rod out of the water ? Thirdly, whether or no that commotion was perceptible to both observers, if the observer at D, was placed upon wax and touched the ground with his iron rod in a dry gravelly field at least 300 yards from the water ?

"As from the situation of the ground, trees, &c. neither of the stations could be seen by each other, or by the observer at the electrifying machine, it was agreed to discharge a gun as a signal to get ready, and to do the same, as near as might be, half a minute before each explosion."

"In these experiments, as well as the former, the coated phial was each time charged as high as it could be ; so that if the difference of the shock to the observers was considerable, it was owing to other causes more than to the phial's being differently electrified."

On page 364 of the same publication Watson draws the following conclusions from these experiments ; viz.,

"From a review of these experiments the following observations may be deduced.

I. That, in all the preceding operations, when the wires have mitted, observers were placed at different parts of the line who received the shocks through their bodies. It is needless to remark that telegraphic receiving instruments of this character would be extremely unsatisfactory in practice.

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been properly conducted, the electrical commotions from the charged phial have been very considerable only, when the observers at the extremities of the wire have touched some substance readily conducting Electricity with some part of their bodies.

II. That the electrical commotion is always felt most sensibly in those parts of the bodies of the observers, which are between the conducting wires, and the nearest and most non-electric substance ; or in other words, so much of their bodies, as comes within the electrical circuit.

III. That, upon these considerations, we infer, that the electrical power is conducted between these observers by any non-electric substances, which happen to be situated between them, and contribute to form the electrical circuit.

IV. That the electrical commotion has been perceptible to 2 or more observers at considerable distances from each other, even as far as 2 miles.

V. That when the observers have been shocked at the end of 2 miles of wire, we infer, that the electrical circuit is 4 miles ; viz. 2 miles of wire, and the space of 2 miles of the non-electric matter between the observers, whether it be water, earth, or both.

VI. That the electrical commotion is equally strong whether it be conducted by water or dry ground.

VII. That if the wires between the electrifying machine and the observers are conducted upon dry sticks, or other substances non-electric in a slight degree only, the effects of the electrical powers are much greater than when the wires in their progress touch the ground, moist vegetables, or other substances in a great degree non-electric.

VIII. That by comparing the respective velocities of Electricity, and sound, that of Electricity, in any of the distances yet experienced, is nearly instantaneous."

In the same connection should be mentioned Dr. Franklin,* who, in 1748, set fire to spirits of wine by a current of electricity sent across the Schuylkill River, using the river and earth as a return circuit. These

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* Concerning Franklin's original experiment of transmitting an electric shock across the Schuylkill and firing spirits of wine thereby, the following description is given by Franklin on page 37, of a work entitled "Experiments and Observations on Electricity, made at Philadelphia in America by Benjamin Franklin, L.L.D. and F.R.S. published in London in 1769 as follows:—

"Chagrined a little that we have been hitherto able to produce nothing in the way of use to mankind; and the hot weather coming on, when electrical experiments are not so agreeable, it is proposed to put an end to them for this season, somewhat humorously, in a party of pleasure, on the Banks of the *Skuylkil.** Spirits, at the same time, are to be fired by a spark sent from side to side through the river, without any other conductor than the water; an experiment which we some time since performed, to the amazement of many.† A turkey is to be killed for our dinner by the *electrical shock*, and roasted by the *electrical jack*, before a fire kindled by the *electrical bottle;* when the healths of all famous electricians in *England*, *Holland*, *France* and *G rmany*, are to be drank in *electrified bumpers*,‡ under the discharge of guns from the *electrical battery*."

* "The river that washes one side of *Philadelphia*, as the *Delaware* does the other; both are ornamented with the summer habitations of the citizens, and the agreeable mansions of the principal people of this colony."

†"As the possibility of this experiment has not been easily conceived, I shall here describe it.—Two iron rods, about three feet long, were planted just within the margin of the river, on the opposite sides. A thick piece of wire, with a small round knob at its end, was fixed to the top of one of

early forerunners of the telegraph belonged to inventions of the immature type and necessarily died without bearing fruit.

Naturally enough about this time interest began to

the rods, bending downwards, so as to deliver commodiously the spark upon the surface of the spirit. A small wire fastened by one end to the handle of the spoon, containing the spirit, was carried a-cross the river, and supported in the air by the rope commonly used to hold by, in drawing the ferry boats over. The other end of this wire was tied round the coating of the bottle; which being charged, the spark was delivered from the hook to the top of the rod standing in the water on that side. At the same instant the rod on the other side delivered a spark into the spoon, and fired the spirit. The electric fire returning to the coating of the bottle, through the handle of the spoon and the supported wire connected with them."

"That the electric fire thus actually passes through the water, has been satisfactorily demonstrated to many by an experiment of Mr. *Kinnerfley's*, performed in a trough of water about ten feet long. The hand being placed under water in the direction of the spark (which always takes the straight or shortest course) is struck and penetrated by it as it passes."

‡ "*An electrified bumper* is a small thin glass tumbler, near filled with wine, and electrified as the bottle. This when brought to the lips gives a shock, if the party be close shaved, and does not breathe on the liquor."

The above humorous description given by Franklin of this informal electric club will, I feel sure, remind my readers of the various electrical meetings of a somewhat similar character that have been held quite recently in cities not far from the "City of Brotherly Love."

be manifested concerning the cause of the curious force, that appeared to be able to so readily transmit its manifestations through the densest metallic substances with such incredible rapidity. Various hypoth-

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It has interested me no little to obtain some further description concerning the aforesaid turkey, that was in those early days as Franklin says "killed" but as we unfortunately now say "electrocuted." I have found a further description concerning this early electrocution in a letter to Mr. Collinson on page 209, of Vol. XLVII. of Philosophical Transactions published in a paper read before the Royal Society on June 6th, 1751.

"As Mr. Franklin, in a letter to Mr. Collinson some time since, mentioned his intending to try the power of a very strong electrical shock upon a turkey, I desired Mr. Collinson to let Mr. Franklin know, that I should be glad to be acquainted with the result of that experiment. He accordingly has been so very obliging as to send an account of it, which is to the following purpose. He made first several experiments on fowls, and found, that two large thin glass jars gilt, holding each about six gallons, and such as I mentioned I had employed in my last paper I laid before you upon this subject, were sufficient, when fully charged, to kill common hens outright; but the turkeys, though thrown into violent convulsions, and then, lying as dead for some minutes, would recover in less than a quarter of an hour. However, having added three other such to the former two, though not fully charged, he killed a turkey of about ten pounds weight, and believes that they would have killed a much larger. He conceited, as himself says, that the birds kill'd in this manner eat uncommonly tender.

"In making these experiments, he found, that a man could, without great detriment, bear a much greater shock than he imagined: for he inadvertently received the stroke of two of these jars through his arms and body when they were very near fully charged. It seemed to him an universal blow throughout eses were framed to account for its origin. I will call your attention to but two of the most famous of these hypotheses; viz., the double fluid hypothesis of Du Fay,* and the single fluid hypothesis of Franklin.

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the body from head to foot, and was followed by a violent quick trembling in the trunk, which went gradually off in a few seconds. It was some minutes before he could recollect his thoughts, so as to know what was the matter; for he did not see the flash, tho' his eye was on the spot of the prime conductor, from whence it struck the back of his hand; nor did he hear the crack, tho' the bystanders said it was a loud one; nor did he particularly feel the stroke on his hand, tho' he afterwards found it had raised a swelling there of a bigness of half a swanshot, or pistol-bullet. His arms and the back of his neck felt somewhat numbed the remainder of the evening, and his breast was sore for a week after, as if he had been bruised. From this experiment may be seen the danger, even under the greatest caution, to the operator, when making these experiments with large jars; for it is not to be doubted, but that several of these fully charged would as certainly, by increasing them, in proportion to the size, kill a man, as they before did the turkey."

"Upon the whole, Mr. Franklin appears in the work before us to be a very able and ingenious man; that he has a head to conceive, and a hand to carry into execution, whatever he thinks may conduce to enlighten the subject-matter, of which he is treating: and altho' there are in this work some few opinions, in which I cannot perfectly agree with him, I think scare anybody is better acquainted with the subject of electricity than himself."

*Du Fay's hypothesis of two electric fluids naturally came to him when he discovered the existence of two distinct kinds of electricity, the vitreous, or that produced by friction on rubbing glass, and the resinous, or that obtained from friction on rubbing resin.

The double fluid hypothesis of electricity of Du Fay taught as follows—

(1). That the phenomena of electricity are due to the presence of two hypothetical, imponderable fluids that are respectively positive and negative.

(2). That the particles of each of these fluids are mutually repellant; that is that the particles of the positive fluid repel other particles of the positive fluid; and, similarly, the particles of the negative fluid repel other particles of the negative fluid.

(3). That the particles of the opposite fluids are mutually attractive; that is that the particles of the positive fluid attract the particles of the negative fluid and vice versa; and, that when they so attract they combine and neutralize each other's effects.

(4). That these two fluids are both attracted by matter, and that they are present in all kinds of matter, in a masked or neutralized condition.

(5). That the act of electrification by friction or other cause, consists in a separation of the two opposite

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Priestley in the work before referred to speaks thus in Vol. II., on page 17:

"WHEN Mr. Du Fay discovered the two opposite species of electricity, which he termed the *vitreous* and *resinous* electricity, he necessarily formed the idea of *two distinct electric fluids*, repulsive with respect to themselves, and attractive of one another. But he had no idea of both species being actually concerned in every electrical operation, and that glass or rosin alone always produced them both. This theory, therefore, was as simple in its application as the other."

fluids, the positive fluid going to, say, the body rubbed and the negative fluid to the rubber.

(6). That the phenomena of electricity are produced by the tendency of the two opposite fluids to recombine and neutralize each other.

The single fluid hypothesis of Franklin* explains

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* Franklin thus describes his electrical hypothesis in a letter to Peter Collinson, Esq., written in Philadelphia, July 11th, 1747.—Quoted by Jared Sparks on page 185, of Vol. V. of his work entitled "The Works of Benjamin Franklin containing Several Political and Historical Tracts not included in any Former Edition, and many Letters Official and private not Hitherto Public."

"But now I need only mention some particulars not hinted in that piece, with our reasonings thereupon ; though perhaps the latter might well enough be spared."

"1. A person standing on wax, and rubbing the tube, and another person on wax drawing the fire, they will both of them (provided they do not stand so as to touch one another) appear to be electrized, to a person standing on the floor ; that is, he will perceive a spark on approaching each of them with his knuckle."

"2. But, if the persons on wax touch one another during the exciting of the tube, neither of them will appear to be electrized."

"3. If they touch one another after exciting the tube, and drawing the fire as aforesaid, there will be a stronger spark between them, than was between either of them and the person on the floor."

"4. After such strong spark, neither of them discover any electricity."

"These appearances we attempt to account for thus. We supelectrical phenomena by the following assumptions:

(1). That the phenomena of electricity are due to the presence of a single imponderable fluid.

(2). That the particles of this fluid are mutually repellant.

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pose, as aforesaid, that electrical fire is a common element, of which every one of the three persons above mentioned has his equal share, before any operation is begun with the tube. A, who stands on wax and rubs the tube, collects the electrical fire from himself into the glass; and, his communication with the common stock being cut off by the wax, his body is not again immediately supplied. B, (who stands on wax likewise) passing his knuckle along near the tube, receives the fire which was collected by the glass from A; and his communication with the common stock being likewise cut off, he retains the additional quantity received. To C, standing on the floor, both appear to be electrized; for he, having only the middle quantity of electrical fire, receives a spark upon approaching B, who has an over quantity; but gives one to A, who has an under quantity. If A and B approach to touch each other, the spark is stronger, because the difference between them is greater. After such touch there is no spark between either of them and C, because the electrical fire in all is reduced to the original equality. If they touch while electrizing, the equality is never destroyed, the fire only circulating. Hence have arisen some new terms among us; we say B (and bodies like circumstanced) is electrized *positively;* A, *negatively.* Or rather, B is electrized *plus;* A, *minus.* And we daily in our experiments electrize bodies *plus* or *minus*, as we think proper. To electrize *plus* or *minus*, no more needs to be known than this, that the parts of the tube or sphere that are to be rubbed, do, in the instant of the friction, attract the electrical fire, and therefore take it from the thing rubbing; the same parts immediately, as the friction upon them ceases, are disposed to give the fire they have received to any body that has less. Thus you may circulate it, as Mr. Watson has shown; you may also accumulate or subtract it, upon or from any body, as you connect that body with the

(3). That the particles of this fluid are attracted by all kinds of matter.

(4). That all kinds of matter contain a certain quantity of the electrical fluid; that when this quantity is present in any body no electrical effects are manifested,

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rubber, or with the receiver, the communication with the common stock being cut off. We think that ingenious gentleman was deceived, when he imagined (in his *Sequel*), that the electrical fire came down the wire from the ceiling to the gun-barrel, thence to the sphere, and so electrized the machine and the men turning the wheel, &c. We suppose it was *driven off*, and not brought on through that wire; and that the machine and man, &c., were electrized *minus*, that is, has less electrical fire in them than things in common."

About this time a hypothesis was framed by Abbé Nollet which endeavored to explain the causes of electrical phenomena and which attracted considerable attention. This hypothesis belonged to the type of hypotheses of two separate fluids or streams. A description of Nollet's hypothesis is thus given on page 384, of Vol. X, of the Philosophical Transactions of the Royal Society:

"I am not only satisfied of the existence of an *effluent* electric matter, which all the world allows, and which shews itself 1000 ways; but many convincing reasons have also assured me, that there is, round every electrified body, an *affluent* matter, which comes to it not only from the ambient air, but likewise from all the other bodies, whether solid or fluid, that are round about, and within a certain distance of it. If these surrounding bodies are of a simple nature, as a stone, a piece of iron, *&c.* nothing issues from them but pure electrical matter: but if they are animals, plants or fruits, or, in a word, any organized bodies, or such, in the pores of which there is any substance capable of giving way to the impulses of the electric matter; this matter will, in issuing forth with the great rapidity, but, that if such body possesses either a surplus or a deficit of the fluid, it manifests electrical excitement.

(5). That positive electrification is due to an excess of the fluid, and negative electrification to a deficit.

Although neither of these hypotheses are accepted at the present day, yet they are convenient for explaining many electrical phenomena; and, even at the present day are so frequently alluded to in electrical literature that I have thought it well to mention them.

These hypotheses account very well for the funda-

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which it is known to have, carry along with it whatever it finds moveable enough to be displaced by it; and by so much will the weight of the body be diminished; the s me effect being here produced by the *affluent* matter, as is produced on electrified bodies by the *effluent*. If you will please to read over my essay, what I advance will be better understood. The increase or diminution of perspiration is not a matter of indifference to the animal œconomy: this new method of increasing it at will may possibly prove of use; it is neither inconvenient nor dangerous; and neither I myself, nor any body else of those on whom I made my experiments, suffered even the least inconveniency from it. One feels neither motion nor heat differing from that of the natural state. Nor did the animals give any signs of uneasiness, while they were electrifying: a little wearniness, and a better appetite, were the only effects ever perceived."

In applying his hypothesis to the explanation of the phenomena of electricity, Nollet asserted that these two opposite effluvia were thrown in opposite directions. In order to avoid the difficulty in explaining why these two streams failed to interfere with one another, he assumed the existence in all matter of two sets of pores, one set where the effluvia came out of the electrified body and another set where it entered it.

mental fact that when electricity is produced by friction, or, indeed, by any other means, the production is invariably of a dual character, as much negative electricity being produced as positive. This, of course, would necessarily follow from either hypothesis.

According to the double fluid hypothesis the excitement is due to the separation of two opposite electricities, the amount of positive electricity liberated will necessarily be sufficient in amount to exactly neutralize the negative electricity.

According to the single fluid hypothesis, the surplus obtained on one body by the act of friction must necessarily equal the deficit left on the other body.

1745 was a memorable year in the history of electrical progress; for, it was in this year that Von Kleist, Dean of the Kathedral of Comin in Pomerania, made the discovery of the Leyden Jar.

If you will endeavor to recall the excitement produced in both scientific and financial circles throughout the world generally, by any one of the more notable achievements in electricity during the past ten or fifteen years, say, for example, the successful production of the incandescent electric light, or the invention of the telephone or the phonograph, you may, perhaps, be able to form some idea of the intense excitement produced in 1745, by the discovery of the Leyden jar or vial.

The times were ripe for this discovery. The attention of investigators in different parts of the world was directed to the electrical force. The invention of the Leyden jar therefore belonged to the type of fruitful inventions, and naturally enough we find several claimants for its first conception. As far as I have been able to trace original records, it would appear that its first discovery was made by Von Kleist,* in 1745, al-

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* Priestley attributes the discovery of the Leyden jar or Phial, as it was then called, to Von Kleist, who communicated the discovery in a letter to Dr. Lieberkuhn above referred to. Von Kleist erroneously believed that part of the force of the phial is contributed to it by the human body. In the letter from which the above quotation (p. 44) is taken we find the following:

"A TIN tube, or a man, placed upon electrics, is electrified much stronger by this means than in the common way. When I present this phial and nail to a tin tube, which I have, fifteen feet long, nothing but experience can make a person believe how strongly it is electrified. I am persuaded, he adds, that, in this manner, Mr. Boze would not have taken a second electrical kiss. Two thin glasses have been broken by the shock of it. It appears to me very extraordinary, that when this phial and nail are in contact with either conducting or non-conducting matter, the strong shock does not follow. I have cemented it to wood, metal, glass, sealing-wax, &c. when I have electrified without any great effect. The human body, therefore, must contribute something to it. This opinion is confirmed by my observing that, unless I hold the phial in my hand, I cannot fire spirits of wine with it."

The Leyden phial takes its name from the fact that Cunæus, a native of Leyden, independently discovered its wonderful powers in accumulating electricity by its means while repeating some experiments with Messrs.

though both Muschenbroeck and Cunæus of Leyden also claim it.

Von Kleist describes his discovery in a letter to Dr. Lieberkuhn of Berlin, dated Nov. 4th, 1745, and read by him to the Academy of Science, in Berlin. I will quote from this letter from Vol. I, p. 103, of Priestley's book:

"When a nail, or a piece of thick brass wire, &c. is

Muschenbroeck and Allamand, Professors in the University of Leyden. For this reason the discovery is frequently referred to as having been made by Muschenbroeck, or by Cunæus. In a communication to the Royal Society made on October 30th, 1746, and published in volume X., of the Philosophical Transactions, on page 296, Watson thus refers to Muschenbroeck's experiments:

"I now proceed to take notice of that surprising effect, that extraordinary accumulation of the electrical power in a phial of water, first discover'd by Professor *Musschenbrœk*, a man born to penetrate into the deepest mysteries of Philosophy: and I hope I shall stand excused, if I enter into a minute detail of the circumstances relating thereto. The experiment is, that a phial of water is suspended to a gun-barrel by a wire let down a few inches into the water through the cork; and this gun-barrel, suspended in silk lines, is applied so near an excited glass globe, that some metallic fringes inserted into the gun-barrel touch the globe in motion. Under these circumstances a man grasps the phial with one hand, and touches the gun-barrel with a finger of the other. Upon which he receives a violent shock through both his arms, especially at his elbows and wrists, and across his breast. This experiment succeeds best, *cæteris paribus*.

1. When the air is dry.
2. When the phial containing the water is of the thinnest glass.
3. When the outside of the phial is perfectly dry.
4. In proportion to the number of points of non-electric con-

put into a small apothecary's phial and electrified, remarkable effects follow; the phial must be very dry, or warm. I commonly rub it over beforehand with a finger, on which I put some pounded chalk. If a little mercury, or a few drops of spirit of wine, be put into it, the experiment succeeds the better. As soon as this phial and nail are removed from the electrifying glass,

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tact. Thus if you hold the phial only with your thumb and finger the snap is small; larger when you apply another finger, and increases in proportion to the grasp of your whole hand.

5. When the water in the phial is heated; which being then warmer than the circumambient air, may not occasion the condensing the floating vapour therein upon the surface of the glass.

From these considerations it is to be observ'd, that this effect arises from electrifying the non-electric water, included in the originally-electric glass; so that whatever tends to make the outside of the glass non-electric by wetting it, as, a moist hand, damp air, or the water from the inside of the phial, defeats the experiment, by preventing the requisite accumulation of the electrical power."

"That a gun-barrel is absolutely necessary to make this experiment succeed, is imaginary; a solid piece of metal of any form is equally useful. Nor have I yet found, that the stroke is in proportion to the quantity of electrified matter; having observed the stroke from a sword as violent as that from a gun-barrel with several excited iron bars* in contact with it."

"I have tried the effect of increasing the quantity of water in glasses of different sizes, as high as four gallons, without in the least increasing the stroke. If filings of iron are substituted in the room of water, the effect is considerably lessen'd. If mercury, much the same as water; the stroke is by no means increased in proportion to their specific gravities, as might have been imagined.†"

"The phial should not be less than can conveniently be grasped.

or the prime conductor, to which it hath been exposed, is taken away, it throws out a pencil of flame so long, that, with this burning machine in my hand, I have taken above sixty steps, in walking about my room. When it is electrified strongly, I can take it into another room, and there fire spirits of wine with it. If while it is electrifying, I put my finger, or a piece of gold,

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I generally make use of those, which hold seven or eight ounces, and fill them about four-fifths with water; and the stroke from one of these, under the same circumstances, is equally strong with that of a *Florence* flask held in the hand, which I have sometimes made use of; though the glass of this last is equally thin with that of the phial, and the quantity of water four times as much. That the stroke therefore is not as the quantity of water electrified, is evident from this experiment. This fact does not depend on my judgment alone, but likewise upon the opinions of several learned Members of this *Society*, who have experienced the greater and less quantity of water."

* If of six men touching each other, and standing upon originally-electrics, one touches the gun barrel, the whole are electrified; all these then must be consider'd, as so much excited non-electric matter. From the aggregate of all these, not more fire is visible upon the touch than from either of them singly.

† In this experiment, and in others, wherein we assert, that the stroke is not increased in proportion to the quantity of electrified matter; it must always be understood, that the excited non electrics themselves are touched, without being contained in originally-electrics, as water in the glass; for otherwise (as will hereafter be specified) the effects of different quantities of matter will be very different."

The comparatively little that was understood at this early date concerning the action of the Leyden jar, as is revealed in the above remarks regarding the size of the jar, etc., is too evident to need comment.

which I hold in my hand, to the nail, I receive a shock which stuns my arms and shoulders."

The most extravagant assertions were made concerning the physiological effects produced by the discharge of the Leyden jar.

In an account given by Cunæus in a letter to Reaumur he describes the effects produced on him by the discharge as follows :

During the excitement throughout the world of letters, generally produced by the discovery of the Leyden jar, numerous experiments were made concerning the ease with which its discharge could pass through a great number of people. Early experiments of this character are described in Vol. X. of the Philosophical Transactions, on page 333, thus

"When the phial has been sufficiently electrified as above, the whole company join hands ; the operator at one extremity of the line grasps the bottom of the electrified phial, and the person at the other extremity touches the wire, which rises above the cork. At that instant, the whole company receives a shock, resembling that in the experiment of the gun-barrel, but not so strong ; for it seems not at all to extend beyond the elbows."

"This is the experiment, which abbé *Nollet* performed upon 180 of the guards, before the king, who were all so sensible of it at the same instant of time, that the surprize caused them all to spring up at once ; as it will indeed force any person to do that subjects himself to the trial ; though the convulsionary motion itself, as I observed before, reaches not beyond the elbows : but the greater or lesser effect depend entirely upon the longer or shorter application of the phial to the electrifying speroid ; and I am credibly informed, that when due precautions have not been taken in this particular, some persons have received such violent shocks, as have benumbed, and impaired, to a certain degree, "I lost my breath, and it was two days before I recovered from the effects of the blow and terror." He adds, "I would not take a second shock for the Kingdom of France."

Another experimenter asserts :

"That he lost the use of his breath for some minutes and then followed so intense a pain along his right arm that he feared permanent injury therefrom."

Still another asserts, that "he suffered great convulsions through his body : that it put his blood in agitation ; that he feared an ardent fever and was obliged to have recourse to cooling medicines."

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the use of their arms for a day or two, before they perfectly recovered themselves. I can assure you, however, from my own experience, that, with the precautions I have already taken notice of, there is no manner of danger, though at the same time a sufficient efficacy may be communicated to the phial, to gratify any one's curiosity : and in this particular I have been the more prolix, lest any bad consequences should happen to the unexperienced."

A similar experiment which was tried at the Convent of the Carthusians in Paris, is thus described on page 335—

"At the grand convent of the *Carthusians* here in *Paris*, the whole community formed a line of 900 toises, by means of iron wires of a proportionable length, between every 2 ; and, consequently, far exceeding the line of the 180 of the guards abovementioned. The effect was, that when the two extremities of this long line met in contact with the electrified phial, the whole company, at the same instant of time, gave a sudden spring, and all equally felt the shock, that was the consequence of the experiment."

From what we know of the types of electrical machines at this early time, and the character of the Leyden jars that were constructed, it is evident that the shocks obtained by these early experimenters must have been of an exceedingly trivial character.*

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*Note for example the following description of an experiment made by Prof. Allamand with a Leyden phial made from an ordinary beer glass as quoted from Vol. X, of the Philosophical Transactions on page 321.

"There is an experiment that Mr. *l'Allamand* has tried; he electrified a tin tube, by means of a glass globe; he then took in his left hand a glass full of water, in which was dipped the end of a wire; the other end of this wire touched the electrified tin tube: He then touched, with a finger of his right hand, the electrified tube, and drew a spark from it, when at the same instant he felt a most violent shock all over his body. The pain has not been always equally sharp, but he says, that the first time he lost the use of his breath for some moments; and he then felt so intense a pain all along his right arm, that he at first apprehended ill consequences from it; tho' it soon went off without inconvenience."

"It is to be remarked, that in this experiment he stood simply upon the floor, and not upon the cakes of resin. It does not succeed with all glasses, and tho' he has tried several, he has had perfect success with none but those of *Bohemia*. He has tried *English* glasses without any effect. That glass with which it best succeeded was a beer-glass."

Or the following experiment made by Professor Musschenbroeck, as described on the same page of the above publication:

"Mr. *Musschenbrœck* the professor has repeated his experiment, holding in his hand a hollow bowl exceeding thin, full of water; and he says he experienced a most terrible pain. He says, the glass must not be at all wet on the outside."

I often amuse myself when reading an early account of an important discovery in science, by endeavoring to place myself in the position of the experimenter, and by entering as far as possible into his hopes and ideas, to picture the effects that he expects to obtain from his experiments. I can readily imagine this early experimenter reasoning somewhat as follows:

"How can I obtain a bottle full of this strange fluid, and, by thus isolating it, study its properties just as I would those of any other fluid? Since glass is a non-conductor, I will place some conducting fluid inside a glass bottle, and will lead the electricity from an electrical machine through a conductor to the inside of this bottle. As soon as I then obtain a bottle full of the fluid, I will remove it from the machine, examine its properties and thus get at its effects."

This is practically what Cunæus did; he placed some water in a small phial, and, passing a bent nail down through the cork into the liquid, hung the apparatus on the prime conductor of an electrical machine. As the apparatus was probably crudely made he steadied it while turning the machine, by holding the phial in his hand. On the charging of the phial, the water formed the inside coating, and his hand the outside coating, and he thus obtained, as he thought, a bottle full of electricity. Stopping the machine he then lifted the phial from the prime conductor, grasping it by the bent nail and in this way effected the discharge. He did, indeed, "*get at its effects*," and was unquestionably astonished at the success of his experiment.

In a treatise on electricity, published in 1795 in three volumes, by Tiberius Cavallo, which by the way gives, perhaps, the most complete account of the progress made by electrical science at the time of its publication, some idea may be gained of the estimate placed at this time on the importance of the discovery of the Leyden jar.

"I shall in general," Cavallo remarks, "only observe, that although the science had, through the indefatigable attention of many ingenious persons, and by the discoveries that were daily produced, excited the curiosity of philosophers, and engaged their attention; yet, as the causes of anything, whether great or small, known or unknown, are seldom much attended to, if their effects are not striking and singular, so Electricity had, till the year 1746, been studied by none but Philosophers. Its attraction could in part be imitated by a loadstone; its light by phosphorous; and, in short, nothing contributed to make electricity the subject of public attention, and excite a general curiosity, until the discovery of the vast accumulation of its powers, in what is commonly called the *Leyden Phial*, which was accidentally made in the year 1745. Then, and not till then, did the study of electricity become general, surprised every beholder, and invited to the houses of Electricians a greater number of spectators, than were before assembled together to observe any philosophical experiments whatever."

"Since the time of this discovery, the prodigious number of electricians, experiments, and new facts that have been daily produced, from every corner of Europe, and other parts of the world, is almost incredible. Discoveries crouded upon discoveries; improvements upon improvements; and the science ever since that time went on with so rapid a course, and is now spreading so amazingly fast, that it seems as if the subject would soon be exhausted, and electricians arrive at an end of their researches; but, however, the *ne plus ultra* is, in all probability, as yet at a great distance, and the young electrician has a vast field before him, highly deserving his attention, and promising further discoveries, perhaps, equally, or more important than those already made."

Before leaving the history of electric progress just before the time of the discovery of the Leyden jar, I can hardly give a better idea of the actual state of the science than by the following extract read before the Royal Society by Dr. J. T. Desaguliers in January, 1741, as quoted from Vol. VIII, page 430, of the Philosophical Transactions.

"About a year or two ago, in a Paper I gave in to the *Royal Society*, I endeavored to establish some general Principles concerning Electricity, from the Consideration of many Experiments, which have been tried by others, as well as some new Experiments by

So much for the Leyden phial at the time of its discovery. It is a curious fact that some of the most important advances in the science of electricity, during

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myself, an Account of which I then gave. Therefore I shall only now repeat my Distinction of all Bodies into two Classes, in respect of Electricity, and make good the Definitions that I gave by some further Experiments ; and though I do not pretend to know the Cause of Electricity in general, yet I hope from a few Laws of Electricity, deduced from *Phœnomena*, to solve most other *Phœnomena*, (though seeming quite unaccountable) so far as they shew what Law of Electricity they depend upon ; and to be able to foretel what will happen to most bodies before the Experiments are tried upon them in an electrical way."

1. "Bodies electric *per se* are such in whom a virtue of attracting and repelling small Bodies at a distance is inherent, though it is not always in Action, so as to produce that Effect. But by rubbing, patting with the Hand, hammering, warming, and sometimes only exposing to dry Air, such Bodies exert the Virtue above-mentioned ; otherwise they are in a Non-electric State."

2. "Non-electric Bodies are such that no electrical Virtue can be excited by any Action upon the Bodies themselves, such as rubbing, warming, *&c.* But an Electric *per se*, when excited, can communicate it's Virtue to a Non-electric, and that Virtue will be received by all the Parts of the Non-electric, (be the Body ever so long or large) and be strongest, being, as it were, collected at that End of the Non-electric, which is farthest from the Place where the Electricity is first received."

3. "A Non-electric, having received Electricity, will communicate to another Body brought to touch it, or only brought pretty near, and that often with a snapping Noise and a small Flash of Light, losing by that Means all it's own Electricity."

4. "An Electric *per se* will become a Non-electric for a time, if it be made wet or moist, and become receptive of Electricity, which it will receive at one End, and carry to the other, where the Electricity will go off with a small Explosion, to impregnate any other Non-electric, which is brought near."

recent times, have been made in the direction of the Leyden phial. I refer especially to the researches of Nikola Tesla and Elihu Thomson, on the effects produced by rapidly alternating discharges at high potential.

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5. "An Electric *per se*, in which Electricity is excited, may become Non-electric by being exposed to moist Air, whose humid Vapour it attracts ; and then, brought to the Fire, or into very dry Air, recover it's Electricity when the Moisture is exhaled again."

6. " An Electric *per se* may be made strongly Electric in Part of it's Length, whilst the other part remains in a Non-electric State."

7. "A Body in a State of Electricity (whether a Non-electric having received Electricity, or an Electric *per se*, excited to Electricity) will attract all Non-electrics, and repel other Bodies that are in a State of Electricity, provided the Electricity be of the same kind."

8 "A Non-electric Body will not retain the Electricity which it receives from an Electric *per se*, unless it be free from touching any other Non-electric body ; but must be suspended or supported by Electrics *per se* touching only them and the Air."

9. " An Electric *per se*, when it is not reduced to a Non-electric State, will not receive Electricity from another Electric *per se*, whose Electricity is excited, so as to run along it's whole Length ; but will only receive it a little Way, being (as it were) saturated with it."

10. "An Electric *per se* will not lose it's Electricity at once, but only the Electricity of such Parts of the Body as have communicated it to other Bodies, or near which Non-electrics have been brought."

11. " When a Non-electric, which has received Electricity, communicates it's Electricity to another, it loses all it's Electricity at once ; and the *Effluvia*, in coming out, strikes the new Body brought near, as well as the Body first made electric."

12. "Excited Electricity exerts itself in a Sphere around the

Perhaps one of the most important electrical investigations that has been made in recent years is that of Nikola Tesla* concerning the effects produced by discharges of alternating currents of high potential at extraordinary frequencies. Tesla has shown by a series of

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Electric *per se ;* or rather a Cylinder if the Body be cylindric."

13. "The Electricity which a Non-electric of great Length (for Example, a hempen string 800 or 900 Feet long) receives, runs from one End to the other in a Sphere of electrical *Effluvia*; But all the supports of this String must be Electrics *per se*."

14. "If this String be branched out into many Strings, the Electricity will run to all their Ends."

15. "If the Non-electric String, which is to receive and carry on the electric *Effluvia*, be not continuous, but has between it's Ends some Electrics *per se*, the *Effluvia*, will stop at the first of them, unless the Interruption or Discontinuation of the Non-electric be short."

*The experiments of Tesla are of such recent date that it is hardly necessary to append but brief extracts concerning them. That I should do so at all is only on account of their exceeding novelty and value.

Entering, as Tesla did, into a domain of electrical science, which was apparently thoroughly explored, he soon showed, by the light of his genius, that it was an almost unknown region. He has shown, for example, that our ideas of the conducting and non-conducting powers of ordinary matter for electrical discharges of moderate frequencies, must be entirely changed for the frequencies employed by him. To such discharges, conductors become absolute non-conductors, and even the best of what are ordinarily termed non-conductors conduct the discharges with marked facility. Then experiments which are unique both for their completeness and scope, that, for discharges of enormous frequency, ordinary conductors become absolutely non-conductors, while such substances as vulcanite and

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again as regards the physiological effects of alternating discharges Tesla shows that at the enormous frequencies which it may be possible to give such discharges, they may lose their deadly character and become rather like the genial sunshine.

In a lecture delivered before the American Institute of Electrical Engineers at Columbia College on the 20th of May, 1891, and published in Vol. VIII., Nos. 6 and 7 of the Transactions of the American Institute of Electrical Engineers, on page 277, Tesla describes a variety of discharges obtained by the use of high frequencies of alternation as follows:

"First, one may observe a weak, sensitive discharge in the form of a thin feebled-colored thread. (Fig. 4.) It always oc-

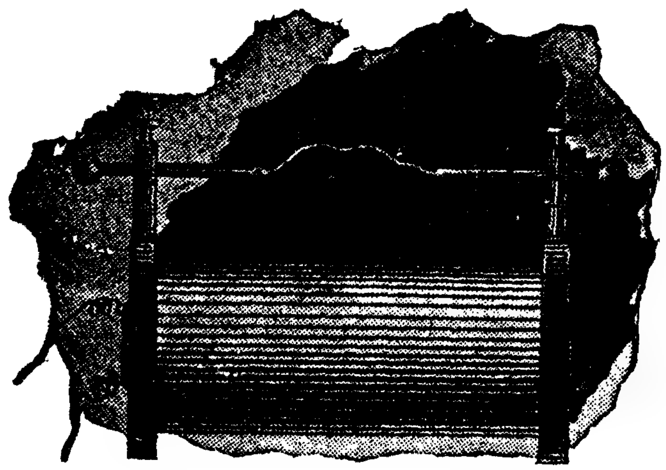

FIG. 4. —SENSITIVE THREAD DISCHARGE.

curs when, the number of alternations per second being high, the current through the primary is very small. In spite of the excessively small current, the rate of change is great and the difference of potential at the terminals of the secondary is therefore considerable, so that the arc is established at great distances;

glass, that for ordinary currents possess the highest powers of insulation, are readily traversed by such discharges. He has proved that the physiological effects of such discharges are less marked than are those of

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but the quantity of "electricity" set in motion is insignificant, barely sufficient to maintain a thin, thread-like arc. It is excessively sensitive and may be made so to such a degree that the mere act of breathing near the coil will affect it, and unless it is perfectly well protected from currents of air, it wriggles around constantly. Nevertheless, it is in this form excessively persistent, and when the terminals are approached to, say one-third of the striking distance, it can be blown out only with difficulty. This exceptional persistency, when short, is largely due to the arc being excessively thin; presenting, therefore, a very small surface to the blast. Its great sensitiveness, when very long, is probably due to the motion of the particles of dust suspended in the air."

"When the current through the primary is increased the discharge gets broader and stronger, and the effect of the capacity of the coil becomes visible until, finally, under proper conditions, a white flaming arc, Fig. 5, often as thick as one's finger and

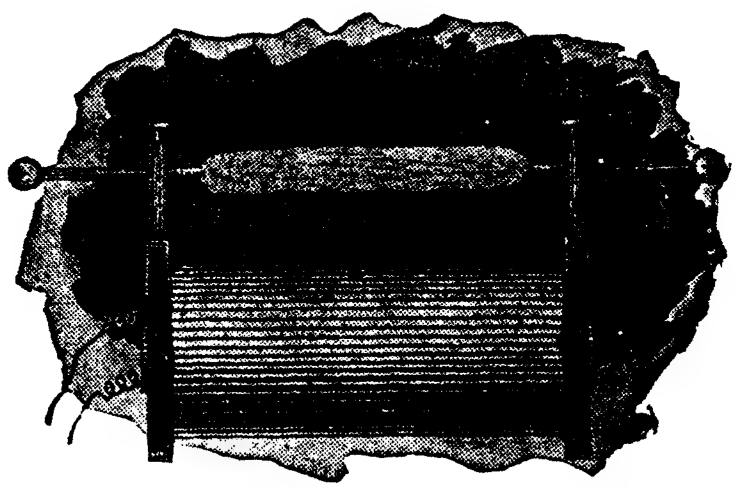

FIG. 5.—FLAMING DISCHARGE.

striking across the whole coil, is produced. It develops remarkable heat, and may be further characterized by the absence of the high note which accompanies the less powerful discharges. To take a shock from the coil under these conditions would not constant currents, or of alternating currents of but moderate frequency.

But what is more interesting about these experiments is their possible commercial bearing. Tesla has pro-

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be advisable, although under different conditions, the potential being much higher, a shock from the coil may be taken with impunity. To produce this kind of discharge the number of alternations per second must not be too great for the coil used ; and, generally speaking, certain relations between capacity, self induction and frequency must be observed."

Then again on page 279,

"When the flaming discharge occurs, the conditions are evidently such that the greatest current is made to flow through the circuit. These conditions may be attained by varying the frequency within wide limits, but the highest frequency at which the flaming arc can still be produced determines, for a given primary current, the maximum striking distance of the coil. In the flaming discharge, the *eclat* effect of the capacity is not perceptible. The rate at which the energy is being stored then just equals the rate at which it can be disposed of through the circuit. This kind of a discharge is the severest test for a coil; the break, when it occurs, is of the nature of that in an overcharged Leyden jar. To give a rough approximation, I would state that with an ordinary coil, of say 10,000 ohms resistance, the most powerful arc would be produced with about 12,000 alternations per second."

"When the frequency is increased beyond that rate, the potential of course rises, but the striking distance may nevertheless diminish, paradoxical as it may seem. As the potential rises, the coil attains more and more the properties of a static machine, until, finally, one may observe the beautiful phenomena of the streaming discharge, Fig. 6, which may be produced across the whole length of the coil. At that stage, streams begin to issue freely from all points and projections. These streams will also be seen to pass in abundance in the space between the primary duced lamps on the principle of bombardment in vacuous spaces, as well as in spaces filled with air at ordinary pressures. He has lighted incandescent lamps one terminal only of which was connected to the source

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and the insulating tube. When the potential is excessively high, they will always appear, even if the frequency be low, and even if

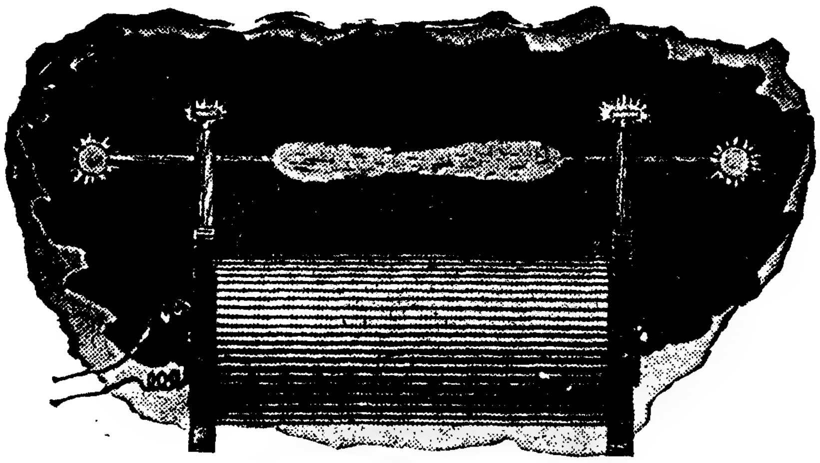

FIG. 6.—STREAMING DISCHARGE.

the primary be surrounded by as much as an inch of wax, hard rubber, glass or any other insulating substance. This limits greatly the output of the coil, but I will later show how I have been able to overcome to a considerable extent this disadvantage in the ordinary coil."

"Besides the potential, the intensity of the streams depends on the frequency ; but if the coil be very large they show themselves no matter how low the frequencies used. For instance, in a very large coil of resistance of 67,000 ohms, constructed by me some time ago, they appear with as low as 100 alternations per second and less, the insulation of the secondary being ¾ inch of ebonite. When very intense, they produce a noise similar to that produced by the charging of a Holtz machine, but much more powerful, and they emit a strong smell of ozone. The lower the frequency, the more apt they are to suddenly injure the coil. With excessively high frequencies, they may pass freely without producing any other effect than to heat the insulation slowly and uniformly."

"The existence of these streams shows the importance of constructing an expensive coil, so as to permit of one's seeing of alternating current. He has even lighted such lamps when their terminals were not connected by any conductor with such source. Indeed, the investigations made by this acute observer has almost opened a new science within that comparatively new science of electricity.

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through the tube surrounding the primary, and the latter should be easily exchangeable, or else the space between the primary and the secondary should be completely filled up with insulating materials, so as to exclude all air. The non-observance of this simple rule in the construction of commercial coils, is responsible for the destruction of many an expensive coil."

"At the stage when the steaming discharge occurs, or with somewhat higher frequencies, one may by approaching the terminals considerably and regulating properly the effect of capacity, produce a veritable spray of small silver-white sparks or a bunch of excessively thin silvery threads (Fig. 7) amidst a powerful

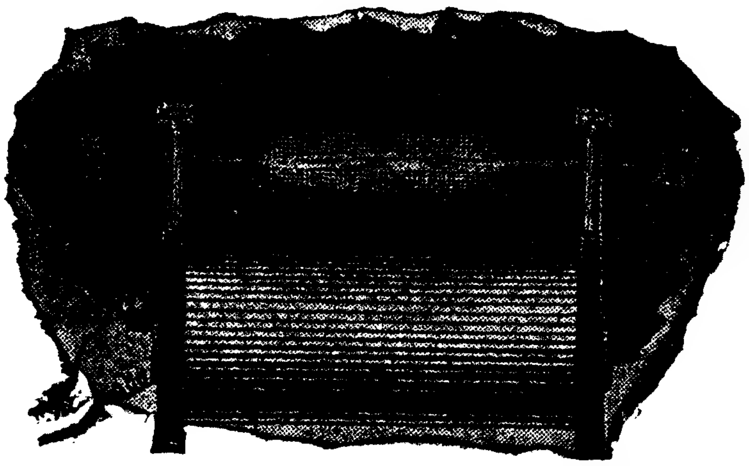

FIG. 7.—BRUSH AND SPRAY DISCHARGE.

brush—each spark or thread possibly corresponding to one alternation. This, when produced under proper conditions, is probably the most beautiful discharge, and when an air blast is directed against it, it presents a singular appearance. The spray of sparks, when received through the body, causes some inconvenience, whereas when the discharge simply streams, nothing at all is likely to be felt if large conducting objects are held in the hands to protect them from receiving small burns."

An exceedingly important discovery concerning the discharge of a Leyden jar, was made in 1842 by Prof. Joseph Henry* of America. This discovery refers to peculiarities concerning the nature of the disruptive discharge of such a jar; and, it is along the line of these peculiarities that most of the recent developments of this instrument were made.

You are probably aware of the fact that when an insulated body, electrified by friction, is connected to the

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*Prof. Henry clearly recognized the oscillatory character of the discharge of a Leyden jar, as will be seen from the following quotation from page 377 of the "Proceedings of the American Association for the Advancement of Science," for 1850, from a paper entitled an "Analysis of the Dynamic Phenomena of the Leyden Jar," by Prof. Joseph Henry:

"Prof. Joseph Henry gave an account of his investigations of the discharge of a Leyden jar. This was a part of a series of experiments he had made a few years ago, on the general subject of the dynamic phenomena of ordinary or frictional electricity. On this subject he had made several thousand experiments. He had never published these in full, but had given brief notices of some of them in the proceedings of the American Philosophical Society. All the complex phenomena he had observed could be referred to a series of oscillations in the discharge of the jar. If we adopt the hypotheses of a single fluid, then we shall be obliged to admit that the equilibrium of the fluid, after a discharge takes place, by a series of oscillations, gradually diminishes in intensity and magnitude. He had been enabled to show effects from five of these waves in succession. The means used for determining the existence of these waves was that of the magnetization of steel needles, introduced into the axis of a spiral. A needle of this kind, it is well known, is susceptible of receiving a definite earth by means of a conductor, it is quietly discharged by what is technically known as a conductive discharge.

If a knuckle of the hand be approached to such a body the discharge occurs by means of a spark which leaps through the air space, separating the charged body from the hand, and, when the discharge is powerful, is attended by a crackling sound or a loud report. Such a discharge is called a disruptive discharge.

If a sharp point or a pin be connected to the conduc-

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amount of magnetism, which is called its saturation. Now, if the needle be of such a size as to be magnetized to saturation by the principal discharge, it will come out of the spiral magnetized to a less degree than that of saturation, by the amount of the adverse influence of the oscillations in the opposite direction to that of the principal discharge. If the quantity of electricity be increased, the power of the second wave may be so exalted that the needle will exhibit no magnetism; the whole effect of the first or principal wave will be neutralized by the action of the second. If the quantity of electricity be greater than this, then the needle will be magnetized in an opposite direction. If the electricity be still more increased, the needle will again exhibit a change in its polarity, and so on in succession as the power of the successive waves is increased."

"These experiments had been made several years ago, but Prof. H. had not given them in detail to the public, because he had wished to render them more perfect. For the last three and a half years, all his time and all his thoughts have been given to the details of the business of the Smithsonian Institution. He had been obliged to withdraw himself entirely from scientific research, but he hoped that now the institution had got underway, and the Regents had allowed him some able assistants, that he would be allowed, in part, at least, to return to his first love—the investigation of the phenomena of nature."

tor, a stream of electrified air particles is thrown off from such point, and will quietly discharge the electrified body by means of what is called a convective discharge.

Now, in a Leyden jar, the opposite charges on the two metallic coatings are held in a bound state by means of their mutual attractions. When these opposite coatings are brought sufficiently near together by means of a conductor a disruptive discharge occurs in the shape of a bright spark attended by a crackling sound. This discharge is apparently instantaneous, but in 1842 Prof. Henry, while studying the peculiar character of the magnetization produced by the discharges of Leyden jars through magnetizing spirals, came to the conclusion that such discharges are truly oscillatory in character; that they are not instantaneous, but consist of a number of separate discharges and recharges occurring in alternately opposite directions. Or, in other words, that the disruptive discharge of a Leyden jar partakes of the nature of an alternating or rapidly periodic discharge.

The character of the magnetization that Henry was studying, was what was then called by the Germans anomalous magnetization. Henry showed that in reality the anomaly was to be traced rather to the peculiar nature of the discharge than to that of the magnetization itself. Quoting Henry's own words in a memoir published in 1842, he says—

"The discharge, whatever may be its nature, is not correctly represented by a single transfer of the imponderable liquid from one side of the jar to the other; the phenomena require us to admit of the existence of a principal discharge in one direction and then several reflex actions backward and forward each more feeble than the preceding, until equilibrium is attained. All the facts are shown to be in accordance with this hypothesis, and a ready explanation is afforded by it of a number of phenomena which are to be found in the older works of electricity, but which have until this time remained unexplained."

Our ideas ot electrical conduction and propagation have been profoundly modified during the past few years, largely by reason of difficulties that have arisen in the distribution of the electric currents employed for feeding incandescent lights that are situated at considerable distances from the source producing the currents. I am, perhaps, justified in the statement that there has thus far been found but one successful means of so distributing such currents economically when the distances exceed certain values. This distribution is effected by means of currents, called alternating currents, because they rapidly change their direction.

In systems of alternating current distribution, currents of comparatively great differences of potential but of small current strength, are sent through a line wire or conductor to the points or places at which their energy is to be utilized. At such points they are sent through devices called transformers, by which they are transformed both as regards their difference of potential and current strength into currents of comparatively small difference of potential but great current strength

This method of distribution is more economical than could be obtained by the use on such lines of continuous currents, from the fact that the size of the conductors can be made very much less for currents of high potential and small current strength, than for those of low potential and great current strength.

Such study, conducted as it was along the lines of actual commercial applications, led to many remarkable discoveries, and I trust you will pardon me if I digress at this point to ask you to briefly consider a topic that is so very often discussed in scientific circles; viz., the relative merits of the so-called pure and the applied sciences. For my own part I do not recognize that sharp distinction between pure and applied science that many of my professional brothers appear to do; but, so far as it does exist, I must confess to a decided belief in the value of the applied over that of the so-called pure sciences. The only difference that I can really see between the two, that can be regarded as of any value, is this; that in the case of an applied science the various hypotheses or speculations that are formed concerning the proper interpretation of the phenomena under discussion, are at once put to the test of extended commercial use; and, thus being worked out in cold material, are at once either accepted or rejected; while it is, unfortunately, too often true in the case of a so-called pure science, that interpretations of their manner of action are obscured by extended explanations of hypothetical causes, and, not being put to the test of actual use, though manifestly improbable, are often kept alive by that strange force of authority, which is now happily growing of less and less importance in the world of science.

However this may be, there has resulted from this practical study of alternating currents, in which the highest and best types of both pure and applied science have been employed, a knowledge of the peculiarities of the flow and other phenomena of such currents that has thrown considerable light on the causes of the electric force itself.

Dr. Hertz, Professor in the University at Bonn, has made the most marked advance in the direction of a theory as to the origin and nature of electric discharges by a careful study of the peculiarities of oscillatory discharges; that is, alternating discharges of high frequency.

Taking, for example, the disruptive discharge of a Leyden jar, Dr. Hertz fixed his attention on the medium lying outside of the conductor, through which the discharge was passing, rather than on the conductor itself. By a series of investigations, conducted not only on discharges obtained from Leyden jars, but also on those obtained from induction coils, the primaries of which were traversed by alternating currents of high frequency, Hertz has shown, by a singularly complete series of investigations, that during such discharge, the ether lying outside the conductor, is moulded into waves that proceed outward in all directions from the conductor with the velocity of light. He has shown that such waves or vibrations are capable of exciting sympathetic vibrations in neighboring conductors provided, of course, the dimensions of such conductors are such as will insure a unison in the rate of vibration between the excited and the exciting waves. Hertz names this phenomenon electrical resonance,* and shows that it exactly resembles acoustic resonance.

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*The term resonance, as used in physical science, referred originally to the case of excited sound waves, and related to sympathetic vibrations excited in certain bodies, notably, in the air contained within hollow vessels, such as shells, or jars, or, in the wood of violins, guitars, or in the sounding boards of pianos. In all cases of resonance, the excited waves are of exactly the same wave lengths as the exciting waves; or, in other words, the pitch or tone of the two is the same.

Hertz extended the principle of acoustic resonance to the case of the electro-magnetic waves that are produced in the space surrounding a conductor through which an electric discharge that alternates in its direction, such for example as a Leyden jar, is passing. He showed that if a circuit be placed near such a conductor

Electric radiation being thus proved to partake of the nature of wave motions, all the phenomena characteristic of wave motions can be shown to exist in such waves. For example, nodes may be formed in conductors

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it will have electric oscillations set up in it, provided its dimensions are such that its period of oscillation is the same as those in the exciting circuit.

As in the case of acoustic resonance, so in the analogous case of electric resonance, the electrical effects produced by the excited waves are similar to those produced by the exciting waves.

In a translation by Tunzelmann, of a note by Hertz in Weidmann's Annalen, published in the London "Electrician," of Sept. 21st, 1888, on page 626, Hertz says—

"In order to determine whether, as some minor phenomena had led the author to suppose, the oscillations were of the nature of a regular vibration, he availed himself of the principle of resonance. According to this principle, an oscillatory current of definite period would, other conditions being the same, exert a much greater inductive effect upon one of equal period than upon one differing even slightly from it."

"If, then, two circuits are taken having as nearly as possible equal vibration periods, the effect of one upon the other will be diminished by altering either the capacity of the coefficient of self-induction of one of them, as a change in either of them would alter the period of vibration of the circuit."

"This was carried out by means of an arrangement very similar to that of Fig. 4. The conductor C C′, was replaced by a straight copper wire 2.6 metres in length and five millimetres in diameter, divided into equal parts as before by a discharger. The discharger knobs were attached directly to the secondary terminals of the induction coil. Two hollow zinc spheres, 30 centimetres in diameter, were made to slide on the wire, one on each side of the discharger, and since, electrically speaking, through which such discharges are passing. Waves may be so superposed on one another, as to produce the phenomena of interference; that is, electric waves or radiations from two sources may be caused to simultane-

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these formed the terminals of the conductor, its length could be varied by altering their position. The micrometer circuit was chosen of such dimensions as to have, if the author's hypothesis were correct, a slightly shorter vibration period than that of C C′. It was formed of a square, with sides 75 centimetres in length, of copper wire two millimetres in diameter, and it was placed with its nearest side parallel to C B C′, and at a distance of 30 centimetres from it. The sparking distance at the micrometer was then found to be 0.9 millimetre. When the terminals of the micrometer circuit were placed in contact with two metal spheres 8 centimetres in diameter, supported on insulating stands, the sparking distance could be increased up to 2.5 millimetres. When these were replaced by much larger spheres the sparking distance was diminished to a small fraction of a millimetre. Similar results were obtained on connecting the micrometer terminals with the plates of a Kohlrausch condenser. When the plates were far apart the increase of capacity increased the sparking distance, but when the plates were brought close together the sparking distances again fell to a very small value."

"The simplest method of adjusting the capacity of the micrometer circuit is to suspend to its ends two parallel wires, the distance and lengths of which are capable of variation. By this means the author succeeded in increasing the sparking distance up to three millimetres, after which it diminished when the wires were either lengthened or shortened. The decrease of the sparking distance on increasing the capacity was naturally to be expected; but it would be difficult to understand, except on the principle of resonance, why a decrease of the capacity should have the same effect."

"The experiments were then varied by diminishing the capacity of the circuit C B C′ so as to shorten its period of oscillation, and the results confirmed those previously obtained, and a series ously impress their peculiar form of energy on a conductor so as either to augment or diminish each other's intensity of action. Electrical waves may be made to suffer reflection, or refraction, or any other phenomena of wave motion as manifested by light or by sound waves.

Prof. Lodge* has made some calculations concerning the rate of oscillation produced by the discharge of an ordinary pint Leyden jar by means of a common discharging rod as being equal to ten millions per second.

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of experiments in which the lengths and capacities of the circuits were varied in different ways, showed conclusively that the maximum effect does not depend on the conditions of either one of the two circuits, but on the existence of the proper relation between them."

"When the two circuits were brought very close together, and the discharger knobs separated by an interval of 7 millimetres, sparks were obtained at the micrometer, which were also 7 millimetres in length, when the two circuits had been carefully adjusted to have the same period. The induced E.M.F.'s must in this case have attained nearly as high a value as the inducing ones."

* Prof. Oliver Lodge in his charming work entitled "Modern Views of Electricity," says concerning the rate of oscillations of an ordinary Leyden jar, on page 248. London: Macmillan & Co., 1889.

"A common pint Leyden jar discharging through a pair of tongs may start a system of ether waves each not longer than about 15 or 20 metres; and its rate of oscillation will be something like ten million per second."

"A tiny thimble-sized jar overflowing its edge may propagate waves only about 2 or 3 feet long."

Of course I have not been able in the limited time of a single lecture to do any more than to give you the briefest outline of these very remarkable investigations. Hertz's views are almost universally adopted by those who have carefully studied the subject.

Let me now briefly call your attention to some of the phenomena concerning what is apparently the simplest of all electrical phenomena; viz., the so-called passage or flow of electricity through a conductor, or, what is called electric conduction.

"The oscillations of currents thus recognized as setting up waves have only a small duration, unless there is some means of maintaining them. How long they will last depends partly upon the conductivity of the circuit; but even in a circuit of infinite conductivity they must die out if left to themselves, from the mere fact that they dissipate their energy by radiation. One may get 10 or 100, or perhaps, even 1,000, perceptible oscillations of gradually decreasing amplitude, but the rate of oscillation is so great that their whole duration may still be an extremely small fraction of a second. For instance, to produce ether waves a metre in length requires 300,000,000 oscillations per second."

"To keep up continuous radiation naturally requires a supply of energy, and unless it is so supplied the radiation rapidly ceases. Commercial alternating machines are artificial and cumbrous contrivances for maintaining electrical vibrations in circuits of finite resistance, and in despite of loss by radiation."

"In most commercial circuits the loss by radiation is probably so small a fraction of the whole dissipation of energy as to be practically negligible; but one is, of course, not limited to the consideration of commercial circuits or to alternating machines as at present invented and used. It may be possible to devise some less direct method—some chemical method, perhaps—for

The flow of electricity through a wire is an apparently simple phenomenon. The excited body is placed at one end of a conductor, and, almost immediately, it produces characteristic phenomena at the other end, although hundreds or even thousands of miles distant. Up to a very recent date it was believed that electricity passed through the substance of a conductor. Perhaps I can best give you the old conception of conduction by quoting from the work of Cavallo before referred to.

"If at the end of the tube opposite to that held in the hand a wire of any length be tied, suspending a metallic ball at its end, the tube be excited as before the metallic ball will, in this case, acquire all the prop-

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supplying energy to an oscillating circuit, and so converting what would be a mere discharge or flash into a continuous source of radiation."

"So far we have only considered ordinary practicable electrical circuits, and have found their waves in all cases pretty long, but getting distinctly shorter the smaller we take the circuit. Continue the process of reduction in size further, and ask what sized circuit will give waves 6000 tenth-metres (three-fifths of a *micron*, or 25 millionths of an inch) long. We have only to put $2\pi\sqrt{\left(\frac{L}{\mu}\frac{S}{K}\right)} = 0.00006$, and we find that the necessary circuit must have a self induction in electro-magnetic units, and a capacity in electrostatic units, such as their geometric mean is 10^{-5} centimetre (one-tenth of a micron). This gives us at once something near atomic dimensions for the circuit, and suggests immediately that those short ethereal waves which are able to affect the retina, and which we are accustomed to call "light," may be really excited by electrical oscillations or surgings in circuits of atomic dimensions."

erties of the excited tube; i. e., it will attract, sparkle, etc., like the tube itself, the electric virtue passing through the wire to the ball: hence, the wire is said to be a *conductor* of electricity; and all such bodies as are capable to transmit the electric virtue, like the above-mentioned wire, are called *conductors*."

"But if, instead of the wire, a silk string be used in the above experiment, and the tube be excited as before, the ball in this case will not show any signs of electricity; the silk string not permitting the electric virtue to pass from the tube to the ball: hence the silk string in this case, and all those substances through which the electric virtues cannot be transmitted, are called *non-conductors*."

Up to comparatively recent dates practically identical views have been held concerning conductors. Quite recently, however, our views have changed profoundly in this respect. According to Hertz, Poynting and others, the energy of electric discharges is not propagated or transmitted through the conductor itself, but through the ether lying outside of the conductor as well as that which fills the interatomic and intermolecular spaces within the conductor. This is the medium which is known in science as the dielectric and is ordinarily looked on as the non-conductor, or as the insulator. For example, in the case of a telegraph wire strung on insulators and passing through the air between two stations, the air and the glass insulate the said conductor from the earth. According to the modern theory of the propagation of electricity, however, the electric energy is in reality transmitted through such non-conducting paths and is rained down on the surface of the conductor from the space outside it, the conductor acting merely as a sink or place where the electric energy can dissipate itself. The electric energy is, therefore, really propagated through the so-called non-conductor and merely expends its energy, or manifests its characteristic effects, on the conductor itself.

Since, as is well known, electric charges are invariably accompanied by magnetic fields, the electric waves or oscillations produced, for example, by the discharge of a Leyden jar or induction coil, are generally referred to as electro-magnetic waves or oscillations.

In order to give you a brief description of these modern notions I cannot do better than to quote from a paper by Prof. Poynting as summarized by Fleming on page 476 of Vol. I, of a charming book entitled, "The Alternate Current Transformer," which I cannot too strongly recommend to you for purposes of study.

"We see, then, that the energy dissipated in each section of the conductor is absorbed into it from the dielectric, and the rate of this supply can be calculated by Poynting's law for each element of the surface. None of the energy of a current travels along the wire, but it enters into it from the surrounding non-conductor, and as soon as it enters it begins to be transformed into heat, the amount crossing successive layers of the wire decreasing till by the time the centre is reached, where there is no magnetic force, it has all been transformed into heat. In the original Paper, another simple case treated is that of a condenser discharged by a wire. In this case, before the discharge, we know that the energy resides in the dielectric between the plates. If the plates are connected by an external wire, according to these views the energy is transferred outwards, along the electrostatic equipotential surfaces, and moves *on* to the wire and is there converted into heat. According to this hypothesis, we must suppose the lines of electrostatic induction running from plate to plate to move outwards as the dielectric strain lessens and whilst still keeping their ends on the plates to finally converge in on the wire and to be there broken up and their energy dissipated as heat. At the same time the wire acquires transient magnetic qualities. This means that some part of the energy of the expanding lines of electrostatic induction is converted into magnetic energy. The magnetic energy is contained in ring-shaped tubes of magnetic force which expand outward from between the plates and then contract in upon some other part of the circuit."

"The whole history of the discharge may be divided into three parts. First, a time when the energy associated with the system is nearly all electrostatic and is represented by the energy of the lines or tubes of electrostatic induction running from plate to plate; second, a period when the discharge is at its maximum, when the energy exists partly as energy associated with lines of electrostatic induction expanding outwards, and partly in the form of closed rings or tubes of magnetic force expanding and then contracting back on the wire; and then, lastly, a period when nearly all the energy has been absorbed or buried in the wire, and has there been dissipated in the form of heat, which is radiated out again as energy of dark or luminous radiation. The function of the discharging wire is to localise the place of dissipation, and also to localise the place where the magnetic field shall be most intense; and all that observation is able to tell us about a conductor which is conveying that which we call an electric current, is that it is a place where heat is being generated, and near which there is a magnetic field. These conceptions lead us to fresh views of very familiar phenomena. Suppose we are sending a current of electricity through a submarine cable by a battery, say, with zinc to earth, and suppose the sheath is everywhere at zero potential, then the wire will be everywhere at a higher potential than the sheath, and the level surfaces will pass through the insulating material to the points where they cut the wire. The energy which maintains the current and which works the needle at the further end, travels through the insulating material, the core serving as means to allow the energy to get into motion or to be continually propagated. This energy sucked up by the core is, however, transformed into heat and radiated again as dark heat. If we adopt the electro-magnetic theory of light, it moves out again still as electro-magnetic energy, but in a different form, with a definite velocity and intermittent in type. We have then in the case of the electric light this curious result—that energy moves in upon the arc or filament from the surrounding medium, there to be converted into a form in which it is sent out again, and through which the same in kind is able to affect our senses."

"In the case of an arc or glow-lamp worked by an alternating current, we have still further the result that the energy which moves in on the carbon is returned again, with no other change than that of a shortened wave-length, and the carbon filament performs the same kind of change on the electro-magnetic radiation as is performed when we heat a bit of platinum foil to vivid incandescence in a focus of dark heat. A current through a seat of electromotive force is therefore a place of divergence of energy from the conducting circuit into the medium, and this energy travels away and is converged and transformed by the rest of the circuit. From this aspect the function of the copper conducting wire fades into insignificance in interest in comparison with the function of the dielectric, or rather of the ether contained in the dielectric. When we see an electric tram-car, or motor, or lamp worked from a distant dynamo, these notions invite us to consider the whole of that energy, even if it be thousands of horse-power per hour, as conveyed through the ether or magnetic medium, and the conductor as a kind of exhaust valve, which permits energy to be continually supplied to the dielectric."

"Consider, for instance, the simple case of an alternating current-dynamo connected to an incandescent lamp by conducting leads. We have in this case a closed conducting loop, consisting partly of the armature wire, partly of the leads, and lastly of the lamp filament. The action of the dynamo when at work consists in alternately inserting into and withdrawing a bundle of lines of magnetic induction from a portion of this enclosed area or loop. The insertion of these lines of force causes an electro-magnetic disturbance which travels away through the enclosed dielectric in the form of some strain or displacement in its most generalised sense. In reaching the surface of the enclosing conductor this wave begins to soak into it, the electro-magnetic energy at the same time dissipating itself in it in the form of heat. By a suitable arrangement of the resistances and surfaces of various portions of the circuit, we are able to localise the principal place of transformation, and to control its rate so as to compel this transformation of energy to take place at a certain rate in a limited portion of the conductor. Energy is then sent out thence again in a radiant form, partly in the form of ether waves capable of exciting the retina of the eye, but very largely in the form of dark heat. The ether, or electro-magnetic medium, is, therefore, the vehicle by which the energy is carried to the lamp, and conveyed away from it in an altered form, and whatever be the translating device employed, the ether is the seat of the hidden operations, which are really the fundamental ones, and the visible apparatus only the contrivances by which the nature of the energy transformation is determined and its place defined."

Passing by a number of highly important discoveries, such for example, as that of electrostatic induction and the action of dielectrics, I will call your attention for a moment to the immortal discovery by Franklin,* in

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* Franklin gives the following description of his kite in a letter dated October 19th, 1752, which was published on page 111, of a book entitled "Experiments and Observations on Electricity, made at Philadelphia in America," by Benj. Franklin, L.L.D. and F.R.S.—

Letter XI. from Benj. Franklin Esq; of Philadelphia.

Oct. 19, 1752.

"As frequent mention is made in public papers from *Europe* of the success of the *Philadelphia* experiment for drawing the electric fire from clouds by means of pointed rods of iron erected on high buildings, *&c.*, it may be agreeable to the curious to be informed that the same experiment has succeeded in *Philadelphia*, though made in a different and more easy manner, which is as follows:

"Make a small cross of two light strips of cedar, the arms so long as to reach to the four corners of a large, thin silk handkerchief when extended; tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite; which being properly accomodated with a tail, loop, and string, will

which, by means of the historic kite, raised in Philadelphia in 1742, he established the identity between lightning and electric discharges, and also of the extremely practical application he made of such discovery in the invention of the lightning rod

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rise in the air, like those made of paper; but this being of silk, is fitter to bear the wet and wind of a thunder-gust without tearing. To the top of the upright stick of the cross is to be fixed a very sharp pointed wire, rising a foot or more above the wood. To the end of the twine, next the hand, is to be tied a silk ribbon, and where the silk and twine join, a key may be fastened. This kite is to be raised when a thunder-gust appears to be coming on, and the person who holds the string must stand within a door or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window. As soon as any of the thunder clouds come over the kite, the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified, and the loose filaments of the twine will stand out in every way, and be attracted by an approaching finger. And when the rain has wet the kite and twine, so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle. At this key the phial may be charged; and from electric fire thus obtained, spirits may be kindled, and all the other electric experiments be performed, which are usually done by the help of a rubbed glass globe or tube, and thereby the sameness of the electric matter with that of lightning completely demonstrated."

B. F.

As may be readily imagined Franklin's experiment created great excitement in scientific circles, and his experiment in drawing electricity from the air was repeated in different parts of the world.

The following description of the experiment of De

Franklin gave directions concerning the proper construction of lightning rods, that were remarkably complete considering the state of electrical science at his time; indeed, it has not been until a comparatively recent date that any question has been called as to the correctness of these directions.

Franklin's directions were substantially as follows— to place somewhere on the outside of the house or

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Romas in this direction is thus described on page 411, et al. of Vol. I, of Priestley's work on electricity before referred to,—

"THE greatest quantity of electricity that was ever brought from the clouds, by any apparatus prepared for that purpose, was by Mr. De Romas, assessor to the presideal of Nerac. This gentleman was the first who made use of a wire interwoven in the hempen cord of an electrical kite, which he made seven feet and a half high, and three feet wide, so as to have eighteen square feet of surface. This cord was found to conduct the electricity of the clouds more powerfully than a hempen cord would do, even though it was wetted; and, being terminated by a cord of dry silk it enabled the observer (by a proper management of his apparatus) to make whatever experiments he thought proper, without danger to himself."

"BY the help of this kite, on the 7th of June 1753, about one in the afternoon, when it was raised, 550 feet from the ground and had taken 780 feet of string, making an angle of near forty five degrees with the horizon; he drew sparks from his conductor three inches long and a quarter of an inch thick, the snapping of which was heard about 200 paces. Whilst he was taking these sparks, he felt, as it were, a cob-web on his face, though he was above three feet from the string of the kite; after which he did not think it safe to stand so near, and called aloud to all the company to retire, as did himself about two feet."

building to be protected a conductor of such material and area of cross section as would permit it to safely convey to the earth the heaviest bolt that is apt to fall

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"THINKING himself now secure enough, and not being incommoded by any body very near him, he took notice of what passed among the clouds which were immediately over the kite; but could perceive no lightning either there or any where else, nor scarce the least noise of thunder, and there was no rain at all. The wind was West, and pretty strong, which raised the kite 100 feet higher, at least, than in the other experiments."

"AFTERWARDS, casting his eyes on the tin tube, which was fastened to the string of the kite, and about three feet from the ground, he saw three straws, one of which was about one foot long, a second four or five inches, and the third three or four inches, all standing erect, and performing a circular dance, like puppets, under the tin tube, without touching one another."

"THIS little spectacle, which much delighted several of the company, lasted about a quarter of an hour; after which, some drops of rain falling, he again perceived the sensation of the cob-web on his face, and at the same time heard a continual rustling noise, like that of a small forge bellows. This was a farther warning of the increase of electricity; and from the first instant that Mr. De Romas perceived the dancing straws, he thought it not adviseable to take any more sparks even with all his precautions; and he again intreated the company to spread themselves to a still greater distance."

"IMMEDIATELY after this came on the last act of the entertainment, which Mr. De Romas acknowledged made him tremble. The longest straw was attracted by the tin tube, upon which followed three explosions, the noise of which greatly resembled that of thunder. Some of the company compared it to the explosion of rockets, and others to the violent crashing of large earthern jars against a pavement. It is certain that it was heard into the heart of the city, notwithstanding the various noises there."

"THE fire that was seen at the instant of the explosion had the shape of a spindle eight inches long and five lines in diamin that particular latitude. This conductor is to terminate at its upper end in one or more points, and to pass at its lower end into permanently moist earth.

Concerning the advanced ideas as to the protection of buildings from lightning in 1795, I will quote from

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eter. But the most astonishing and diverting circumstance was produced by the straw, which had occasioned the explosion, following the string of the kite. Some of the company saw it at forty five or fifty fathoms distance, attracted and repelled alternately, with this remarkable circumstance, that every time it was attracted by the string, flashes of the fire were seen, and cracks were heard, though not so loud as at the time of the former explosion."

"IT is remarkable, that, from the time of the explosion to the end of the experiments, no lightning at all was seen, nor scarce any thunder heard. A smell of sulphur was perceived, much like that of the luminous electric effluvia issuing out of the end of an electrified bar of metal. Round the string appeared a luminous cylinder of light, three or four inches in diameter: and this being in the day-time Mr. De Romas did not question but that, if it had been in the night, that electric atmosphere would have appeared to be four or five feet in diameter. Lastly, after the experiments were over, a hole was discovered in the ground, perpendicularly under the tin tube, an inch deep, and half an inch wide, which was probably made by the large flashes that accompanied the explosions."

"AN end was put to these remarkable experiments by the falling of the kite, the wind being shifted into the East, and rain mixed with hail coming on in great plenty. Whilst the kite was falling, the string came foul of a penthouse; and it was no sooner disengaged, than the person who held it felt such a stroke in his hands, and such a commotion through his whole body, as obliged him instantly to let it go; and the string, falling on the feet of some other persons, gave them a shock also, though much more tolerable."

the work of Cavallo before referred to. Speaking of the conditions necessary for the proper operation of rods Cavallo says :

"1. That the rod be of such substances as are, in their nature, the best *conductors* of electricity."

Prof. Richman of St. Petersburgh was not as fortunate in avoiding the dangers of thus playing with the thunder-bolts of Jove. While conducting similar experiments he received a fatal discharge. Priestley gives the following description of this sad accident on page 416, of the before-mentioned book; viz.:

"BUT the greatest sufferer by experiments with lightning since mankind have introduced so dangerous a subject of their inquiries, was professor Richman of Petersburgh before mentioned. He was struck dead, on the 6th of August 1753, by a flash of lightning drawn by his apparatus into his own room, as he was attending to an experiment he was making with it. There were two accounts of this fatal accident communicated to the Royal Society, one by Dr. Watson who had it from the best authority; and the other translated from the High Dutch. From both these the following is extracted."

"THE professor had provided himself with an instrument which he called an *electrical gnomon*, the use of which was to measure the strength of electricity. It consisted of a rod of metal terminating in a small glass vessel, into which (for what reason I do not know) he put some brass filings. At the top of this rod, a thread was fastened, which hung down by the side of the rod when it was not electrified; but when it was, it avoided the rod, and stood at a distance from it, making an angle at the place where it was fastened. To measure this angle, he had the arch of a quadrant fastened to the bottom of the iron rod."

"HE was observing the effect of the electricity of the clouds, at the approach of a thunder storm, upon this gnomon; and, of course, standing with his head inclined towards it, accompanied

2. "That the rods be *uninterrupted,* and perfectly *continuous.*"

3. "That they be of *sufficient thickness.*"

4. "That they be perfectly connected with the *common stock.*"

5. "That the upper extremity of the rods be as *accurately* pointed as possible."

6. "That it is *very finely tapered.*"

7. "That it be *prominent.*"

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by Mr. Solokow (an engraver, whom he frequently took with him, to be a joint observer of his electrical experiments, in order to represent them the better in cuts) when this gentleman, who was standing close to his elbow, observed a globe of blue fire, as he called it, as big as his fist, jump from the rod of the gnomon towards the head of the professor, which was, at that instant, at about a foot distance from the rod. This flash killed Mr. Richman, but Mr. Solokow could give no account of the particular manner in which he was immediately affected by it; for, at the same time that the professor was struck, there arose a sort of steam, or vapour, which intirely benumbed him, and made him sink down upon the ground; so that he could not remember even to have heard the clap of thunder, which was very loud."

"THE globe of fire was attended with a report as loud as that of a pistol: a wire, which brought the electricity to his metal rod, was broken to pieces, and its fragments thrown upon Mr. Solokow's cloaths. Half of the glass vessel in which the rod of the gnomon stood was broken off, and the filings of metal that were in it were thown about the room."

"UPON examining the effects of the lightning in the professor's chamber, they found the door case half split through, and the door torn off, and thrown into the room. They opened a vein of the breathless body twice, but no blood followed, and endeavoured to recover sensation by violent chafing, but in vain. Upon

8. "That each rod be carried, in the *shortest convenient direction,* from the point at its upper end, to the *common stock.*"

9. "That there is neither *large* nor prominent bodies of metal upon the top of the building proposed to be secured, but such as are *connected with the conductor* by some proper metallic communication."

10. "That there be a sufficient *number* of high and pointed rods: and"

11. "That every part of the rod be very *substantially* erected."

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turning the corpse with the face downwards, during the rubbing, an inconsiderable quantity of blood ran out of the mouth. There appeared a red spot on the forehead, from which spirted some drops of blood through the pores, without wounding the skin. The shoe belonging to the left foot was burst open, and uncovering the foot at that place, they found a blue mark; from which it was concluded, that the electrical force of the thunder, having entered the head, made its way out again at that foot."

"UPON the body, particularly on the left side, were several red and blue spots, resembling leather shrunk by being burnt. Many more blue spots were afterwards visible over the whole body, and in particular over the back. That upon the forehead changed to a brownish red, but the hair of the head was not singed, notwithstanding the spot touched some of it. In the place where the shoe was unripped, the stocking was intire; as was the coat everywhere, the waistcoat only being singed on the foreflap, where it joined the hinder; but there appeared on the back of Mr. Solokow's coat long narrow streaks, as if red hot wires had burned off the nap, and which could not be well accounted for."

"WHEN the body was opened the next day, twenty-four hours after he was struck, the cranium was very intire, having no

With, perhaps, the exception of insisting more pronouncedly on the necessity for grounding the rod, modern investigations, up to the time of Lodge's study of the lightning rod, had added very little to the requirements for a good rod.

As a lightning discharge that passes from the clouds to the earth generally takes the shortest path, tall objects are the most apt to receive such discharges. Ships at sea are, therefore, very liable to be injured by lightning, and until Wm. Harris, in 1852, proposed a system for the electrical preservation of vessels many good ships were destroyed by such discharges.

Harris' proposition to place lightning rods on ships,

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fissure, nor cross opening ; the brain was found as it possibly should be, but the transparent pellicles of windpipe were excessively tender, gave way, and easily rent. There was some extravasated blood in it, as likewise in the cavities below the lungs ; those of the breast being quite sound, but those towards the back of a brownish black colour, and filled with more of the above mentioned blood : otherwise, none of the entrails were touched ; but the throat, the glands, and the thin intestines were all inflamed. The singed leather-coloured spots penetrated the skin only. Twice twenty-four hours being elapsed, the body was so far corrupted that it was with difficulty they got it into a coffin."

The reasons which led Franklin to suspect the identity of the lightning flash and the electric discharge, are thus given by him in a letter to Dr. L—— of Charlestown, S. C., dated March 18th, 1755, and published on page 322 of his book entitled "Experiments and Observations on Electricity made at Philadelphia:"—

"Your question, how I came first to think of proposing the like many propositions made by scientific men for the good of mankind, was first received with very great disfavor by the public. Prior to Harris' time, some little attempt had been made to protect ships from lightning. The work, however, was clumsily done. The rods were passed along the masts of the vessel, often but a single rod on the mainmast, which was carefully separated from any mass of metal in the ship and passed down into the water from the end of the bowsprit. Such a lightning rod, like an incompetent physician or lawyer, is worse than useless, indeed, is dangerous, and considerable discredit was thrown on the protective power of lightning rods for such reason.

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experiment of drawing down the lightning, in order to ascertain its sameness with the electric fluid, I cannot answer better than by giving you an extract from the minutes I used to keep of the experiments I made, with memorandums of such as I purposed to make, the reasons for making them, and the observations that arose upon them, from which minutes my letters were afterwards drawn. By this extract you will see that the thought was not so much "an out-of-the-way one," but that it might have occurred to any electrician."

"Nov. 7, 1749. Electrical fluid agrees with lightning in these particulars: 1. Giving light. 2. Colour of the light. 3. Crooked direction. 4. Swift motion. 5. Being conducted by metals. 6. Crack or Noise in exploding. 7. Subsisting in water or ice. 8. Rending bodies it passes through. 9. Destroying animals. 10. Melting metals. 11. Firing inflammable substances. 12. Sulphureous smell. The electric fluid is attracted by points. We do not know whether this property is in lightning. But since they agree in all the particulars wherein we can already compare them, is it not probable they agree likewise in this? Let the experiment be made," Harris suggested the necessity for connecting the lightning rods with the copper sheathing of the ship's bottom, and with all masses of metal in the ship, especially with the metallic covering of the outside of the powder magazines. He was regarded as an innovator of the most dangerous type; but when, after considerable opposition, his system was tried and proved to be safe, his most violent critics turned mental somersaults and proclaimed him a public benefactor. Indeed, so highly were his services appreciated by the English Government, that in 1847 he received the honor of knighthood, and is now generally known in science as Sir William Snow Harris.

An amusing story is told concerning the conferring of this honor. So little did Harris expect it, that when he received a public notification of its grant from Earl Russell, he believed that it was a hoax; and, in order to ascertain whether this belief was correct or not, he took the letter to a gentleman residing at Plymouth and asked him, "Have you not a collection of autographs including that of Sir John Russell?" The autograph was produced, and, after carefully examining it, he said, "No, it is no hoax; the writing in my note is identical with that in yours."*

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* The history of any great invention is almost invariably a history of repeated struggles and difficulties. These difficulties arise from a variety of circumstances. Namely,

Prof. Oliver Lodge, bearing in mind the oscillatory character of a disruptive discharge, has recently applied modern ideas concerning such discharges to the case

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(1.) Those of obtaining the exact conditions necessary in order to make the invention operative.

(2.) Those arising from the poverty of the inventor or discoverer.

It too frequently happens that the inventor or discoverer has given his time so uninterruptedly to the particular discovery or invention, that he has neglected his ordinary business, and has, for the time being, if not for all times, impoverished himself.

(3.) Difficulties arising from the unwillingness of an unthinking public to adopt new ideas, together with the general opposition that exists to change or reform of any character.

The history of Harris' improvement of lightning rods, especially as applied to the protection of ships at sea, is no exception to the general rule. The following account of the difficulties that he encountered is thus charmingly described in a biographical notice of Harris by Chas. Tomlinson, F.R.S., on page xv of a "Treatise on Frictional Electricity, in Theory and Practice," by Sir William Snow Harris, F.R.S. London: Virtue & Co., Ivy Lanes, Paternoster Row, 1867.

"Few persons are aware of the long continued struggle Harris had to undergo to impress upon the public mind the importance of adopting his system of lightning conductors for the ships of the Royal Navy, and few are aware of the varied means used for the purpose. He contributed a number of papers to the *Nautical Magazine* illustrative of damage by lightning; he was always on the watch for the slightest scent of a good case; and of lightning rods. He distinguishes two kinds of discharges as taking place between the earth and a charged cloud; namely,

(1.) A steady strain or current.

(2.) An impulsive or oscillatory discharge.

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he never gave it up until he had tracked it to the ship's log deposited in Somerset House, or obtained an account from the Captain or one of the officers of the ship that had been struck. He embodied these cases in letters and pamphlets, which he circulated among Members of Parliament and various persons in authority, including the foreign ambassadors; and it may be mentioned to the honour of the Emperor of Russia, that Harris's system was adopted in the Russian Navy before it was fully admitted into our own. In 1845 the Emperor presented Harris with a valuable ring and a superb vase, in acknowledgment of the merits of his system. Harris also instituted a series of experiments on a large scale, in Plymouth Sound, showing that he could direct the discharge to any point of the vessel, or to the sea, at pleasure; and he made the points of discharge evident by firing gunpowder. These experiments attracted public notice, and crowds assembled on the Hoe to witness them. This led to a ludicrous circumstance, which Harris related to the editor with great glee. One evening an old woman was passing along the Hoe, when a man called her attention to summer lightning that was flashing in the horizon. "Don't talk to me about summer lightning," remonstrated the incredulous dame; "it is that Dr. Harris playing some of his tricks. If he doesen't take care, he will play them once too often."

"Harris not only interested himself in protecting ships from lightning, but he also endeavoured to get his system applied to public buildings. He drew up a long list of buildings that had been damaged, not nearly so full and complete as his list of ships, but still a formidable indictment against folly and prejudice. He even addressed a memorial to a Church Building Society, pointing out the necessity of protecting every new church that was

The former discharge occurs when a cloud gradually approaches a point on the earth; the second occurs when a cloud discharges suddenly to the earth. Lodge

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built. He invited the editor to accompany him to hear the verbal reply, which was to this effect, that the cost of fitting conductors to a church—viz., from £60 to £100—was a fatal objection; for in many cases this additional charge to the estimates would most likely turn the scale against the church being built at all."

"At length all difficulties in the way of his long cherished object were overcome or removed. All the various objections to his conductors had been met : persons in authority had declared that letting the copper bands into the masts weakened them ; but Harris proved experimentally that their powers of resistance to flexure were increased. The flagstaff of a ship, placed on the top of the mast above the point where the conductors began, had been struck by lightning and shivered to pieces. This and similar slight accidents, which really proved the efficiency of the system, at length were so clearly understood, that no further doubt remained. It was felt that some public recognition was due to the man who had made our ships safe from the attack of a destructive foe which had formerly deprived the country of the full services of its navy, killed or crippled its sailors, and wasted many thousands annually of the public money. In 1847 the honor of knighthood was conferred on Snow Harris at the express command of her Majesty the Queen, in consideration of his "very useful inventions," to use the words of Earl Russell. So little was this honour expected, that when Earl Russell's letter arrived at Plymouth, Harris thought it was a hoax ; for he, in common with all men of genius, has a strong sense of humour (without which, indeed, genius seems to be scarcely complete, unless *power* take its place, as in the case of Milton and Dante), and this humour was so often let loose upon his friends in good-natured jokes (often practical ones), that no wonder if he were sometimes repaid in his own coin. He took the letter to a gentleman in Plymouth, and said, 'Have you not a collection of autographs, including that of Lord John Russell?' The autograph in question asserts that iron forms as good a substance for a lightning rod as copper, and although he agrees with the plan generally followed of connecting all masses of metals such as tin roofs, cornices, and gutter spouts with the

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was produced. He examined it carefully, and said, 'No, it is no hoax; the writing in my note is identical with that in yours.' But even then he consulted with his friends whether he had not better ask leave to decline the honour; but he was nervously anxious not to appear in the slightest degree to oppose himself to her Majesty's gracious wish. He accordingly came up to town and received the well-merited honour. The editor called on him next day to congratulate him, when he gave an amusing description of his own feelings on finding himself for the first time in a court-dress. He expressed himself extremely gratified at the gracious manner of the Queen, and the smile of recognition he received from the Prince Consort. Indeed, the confidence of her Majesty and the Prince in the perfect safety of Harris's conductors was shown in a request that he would fit up conductors at Buckingham Palace and at Osborne, and also similarly protect her Majesty's yacht. Harris was also employed some years later to design a complete system of conductors for the palace at Westminster. His written instructions, which are full of interest, were ordered by the House of Commons to be printed, and they will be found under the head of 'Estimates, &c., Civil Services, for the year ending March 31st, 1856.'"

"There was now no difficulty in the way of admitting Harris's conductors into the Royal Navy, and the Government, in consideration of his great services, proposed a vote of £5000 to the inventor. Sir James Graham, in moving the vote, said that he never voted away money with more pleasure."

"In 1850 Sir William was elected an honorary member of the Naval Club at Plymouth, when a number of eminent officers warmly congratulated him on the great service he had rendered to the Navy. In 1854 he was elected an honorary member of the Royal Yacht Squadron at Cowes, by the consent of all the members, in acknowledgment of his public services. Nothing could rod, yet he asserts that such connections should preferably be made by separately grounded conductors rather than directly by the rod itself.

He also discountenances the direct connection of the lightning rod with the building that is to be protected, and prefers to have such rod detached from the building

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be more congenial to Sir William's tastes, for he was always more of a sailor than a landsman. His very walk reminded you of the deck of a ship, and the warmth and simplicity of his character, of a sailor. It was quite a treat to be with Harris near or on the sea. There was not a craft that he was ignorant of, and he was never tired of pointing out the merits and defects of the vessels around him. He loved to be on the sea, in whatever craft. The editor once accompanied him to the Eddystone in the lighthouse tender, and on another occasion to Cornwall in a limestone barge. He had invented a new form of ship's compass in which he took great interest, and was proud to see it in use. Being told that a yacht had arrived in the Sound with one of his compasses on board, he asked the editor to go with him to inquire how the yachtsman liked it. As soon as he got on board and sent in his message, the proprietor came up and said, 'Oh! I don't like your compass at all; but I have one here by a man named Harris that is a great favourite of mine.' 'I'm Harris,' was the bursting, eager reply, whereupon apologies and warm congratulations ensued."

"Sir William had long had a yacht of his own, in the management and sailing of which he took the greatest delight. He was proud of his nautical skill, and was pleased when some one told him that a naval man once observing a sailing-boat tacking about the Sound, exclaimed, 'Egad, the fellow in that boat well knows what he's about!' It need hardly be said that the fellow was Harris himself. He had many other characteristics of a sailor, but there is one point in which he did not resemble Jack Tar: that is, in his indifference to dancing, although, as we have said, he was an accomplished musician."

by means of good glass insulators. He also recommends the use of a stranded conductor rather than the solid conductors generally employed.*

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* There is even yet no little diversity of opinion concerning the exact conditions that should be fulfilled in order to best ensure lightning protection. The question of lightning protection came up before the "Meeting of the British Association at Bath in 1888, and considerable discussion followed. Prof. Lodge, in a sketch of the electrical papers read before Section A, of such meeting, thus ably and humorously describes the discussion in the London "Electrician,"—I quote from a reprint in the "Electrical Engineer," N. Y., Vol. VII, 1888, page 537:—

"And now we have cleared the course for the lightning rod discussion, which excited a good deal of interest, and which really was a discussion, in which many prominent members of the section took part, and on which much more might have been said had there been time."

"The discussion is being reported in this journal pretty nearly verbatim; but out of such a mass of matter it would be difficult for any one to pick out the salient points of difference between the opposite camps, and it may be useful to bring them into more marked relief."

"The opposite camps may be styled the Practical *vs.* the Theoretical. On the one side we find constructors of lightning rods, members of the lightning rod conference, meteorologists, and engineers; a miscellaneous body of great experience headed for the time being with efficiency and good humor by the president of Section G, who has necessarily in his official position an enormous number of lightning protectors under his supervision."

"On the other side we find some laboratory experiments, and a theory of the alternating character of a discharge, combined with a mania for talking about self-induction or electro-magnetic inertia, and for poking this idea into a lot of places where it does not naturally seem to fit ; excluding its influence, however, from other places where one would expect to find it, such as the interior of an iron rod."

"If views and statements so founded are to make headway against the experience of practical men, and to gradually introduce reform into existing procedure, it must be by reiterated statement and discussion, and after gradually acquired further experience under circumstances and conditions arranged to test the new views on a large scale. On the other hand, if the self-induction mania has no sound basis in fact, the surest way of destroying it is to bring it into the arena and expose it to conflict. Hence it is that the organizing committee of Section A arranged for the opposite camps to meet and skirmish at Bath."

"The combat was not waged to the death, the lists being cleared before the combatants were half exhausted, so that it is quite possible that they may meet again on some other arena. Meanwhile, the points at issue may be summarized thus: selecting those statements of Mr. Preece and his supporters which seem most generally accepted, or likely to be accepted, on that side; and numbering the opposing statements so as to correspond with them. No statement is here quoted or suggested which, to the writer, seems entirely absurd ; because absurd statements may easily be made in debate without sufficient thought, and because such statements are not likely to be generally or weightily accepted, even if pressed by their propounder."

Statements made in the Practical Camp

1. Properly constructed lightning rods never fail. When existing rods fail it is because there is something the matter with them—usually an insufficient earth.

Statements made in the Theoretical Camp.

1. Rods as at present constructed, though frequently successful, may and do sometimes fail, even though their earth is thoroughly good ; the reason being that they offer to a flash a much greater obstruction —a much worse path—

than is usually supposed; an obstruction to be reckoned in hundreds or thousands of ohms, even for a very thick copper wire.

2. Leyden jar discharges have nothing oscillatory or alternating about them, or at least the existence of such alternations is an unproved assumption.

2. When a Leyden jar is charged it corresponds to a bent spring, and its discharge corresponds to the release of the spring. Its discharge current alternates, therefore, in the same way and for much the same reason as a twitched reed or tuning fork vibrates. The vibrations decay in either case because of frictional heat production, and because of the emission of waves into the surrounding medium. A single spark of a Leyden jar, examined in an exceedingly fast revolving mirror, is visibly drawn out into a close succession of oppositely-directed discharges, although its whole duration is so excessively minute.

3. Even if Leyden jar discharges should turn out to be oscillatory, there is no reason why lightning flashes should be of the same character. Lightning flashes have an apparent duration, and transmit telegraph signals, deflect compass needles, and do other things which alternating currents could not do.

3. A lightning flash is a spark between cloud and earth, which are two oppositely electrified flat surfaces, and the flash corresponds therefore to the internal sparking between the two plates of a great air condenser. All the conditions which apply to a Leyden jar under these circumstances are liable to be true for lightning.

Sometimes the resistance met with, either in the cloud itself or in the discharger, may be so great that the spark ceases to be oscillatory, and degenerates into a fizz or rapid leak; but there can be no guarantee that it shall always take this easily manageable form; and it is necessary in erecting protectors to be prepared for the worst and most dangerous form of sudden discharge. The apparent duration of a lightning flash is due to its frequently multiple character, and indicates successive discharges, not one long-drawn out one. Nothing that lightning has been found to do disproves its oscillatory character; because Leyden jar discharges, which are certainly oscillatory, can do precisely the same.

4. The one thing needful for an efficient lightning protector is conductivity, sufficient conducting power to convey the whole charge quickly and harmlessly down to the earth, with which the conductor must make elaborate contact.

4. Although some conductivity is necessary for a lightning conductor, its amount is of far less consequence than might be expected. The obstruction met with by an alternating or rapidly varying discharge depends much more on electromagnetic inertia or self induction than upon common resistance. So much obstruction is due to this inertia that a trifle more or less of frictional resistance in addition, matters practically not

at all. It is very desirable to have a good and deep earth in order to protect foundations and gas and water mains from damage, and in order to keep total impedance as low as possible.

5. No danger is to be feared from a lightning conductor if only it will be well earthed and be sufficiently massive not to be melted by a discharge. All masses of metal should be connected to it, that they may be electrically drained to earth.

5. The obstruction offered by a lightning rod to a discharge being so great, and the current passing through it at the instant of the flash being enormous, a very high difference of potential exists between every point of the conductor and the earth, however well the two are connected; hence the neighborhood of a lightning conductor is always dangerous during a storm, and great circumspection must be exercised as to what metallic conductors are wittingly or unwittingly brought near or into contact with it. When a building is struck the oscillations and surgings all through its neighborhood are so violent that every piece of metal is liable to give off sparks, and gas may be lighted even in neighboring houses. If one end of a rainwater gutter is attached to a struck lightning conductor the other end is almost certain to spit off a long spark, unless it is also metallically connected. Electric charges splash about

in a struck mass of metal, as does the sea during an earthquake or when a mountain top drops into it. Even a small spark near combustible substances is to be dreaded.

6. The shape of the sectional area of a conductor is quite immaterial; its carrying power has nothing to do with extent of surface; nothing matters in the rod itself but sectional area or weight per foot run, and conductivity.

6. The electrical disturbance is conveyed to a conductor through the ether or space surrounding it, and so the more surface it exposes the better. Better than a single rod or tape is a number of separate lengths of wire, each thick enough not to be easily melted, and well separated so as not to interfere with each other by mutual induction.

The liability of rods to be melted by a flash can be easily over-estimated. A rod usually fails by reason of its inertia-like obstruction, and consequent inability to carry off the discharge without spittings and side flashes; it very seldom fails by reason of being melted. In cases where a thin wire has got melted, the energy has been largely dissipated in the effort, and it has acted as an efficient protector; though, of course, for that time only. Large sectional area offers very little advantage over moderately small sectional area, such as No. 5 B. W. G.

7. Points, if sharp, should

7 Points, if numerous

constitute so great a protection that violent flashes to them ought never to occur.

enough, serve a very useful purpose in neutralizing the charge of a thunder-cloud hovering over them, and thus often prevent a flash; but there are occasions, easily imitated in the laboratory, when they are of no avail; for instance, when one upper cloud sparks into a lower one, which then suddenly overflows to the earth. In the case of these sudden rushes, there is no time for a path to be prepared by induction, no time for points to exert any protective influence, and points then get struck by a violent flash just as if they were knobs. Discharges of this kind are the only ones likely to occur during a violent shower; because all leisurely effects would be neutralized by the raindrops better than an infinitude of points.

8. Lightning conductors, if frequently tested for continuity and low resistance by ordinary galvanic currents, are bound to carry off any discharge likely to strike them, and are absolutely to be depended upon. The *easiest* path protects all other possible paths.

8. The path chosen by a galvanic current is no secure indication of the course which will be taken by a lightning flash. The course of a trickle down a hillside does not determine the path of an avalanche. Lightning will not select the easiest path alone; it can distribute itself among any number of possible paths, and can make paths for itself. Ordinary testing of conductors, therefore, is no guaran-

tee of safety, and may be misleading. At the same time it is quite right to have some system of testing and of inspection, else rust and building alterations may render any protector useless.

9. A certain space contiguous to a lightning rod is completely protected by it, so that if the rod be raised high enough a building in this protected region is perfectly safe.

9. There is no space near a rod which can be definitely styled an area of protection, for it is possible to receive violent sparks or shocks from the conductor itself. Not to speak of the innumerable secondary discharges which, by reason of electro-kinetic momentum and of induction and of the curious recently discovered effect of the ultra-violet light of a spark, are liable to occur as secondary effects in the wake of the main flash.

"Just one word on the subject of iron *vs.* copper. The writer last year thought and stated that, in so far as the substance of the conductor was magnetized by the discharge, iron would obstruct a lightning flash or any other rapidly varying current enormously more than copper does. But the fact is, that the substance of a conductor is, by sufficiently rapidly alternating currents, not magnetized at all. The current is tubular, keeps wholly to the outer surface, and magnetizes nothing inside. Hence the magnetizability of the substance of a conductor is of no moment at all; and iron, therefore, will do every bit as well as copper. Mr. Preece's experience with half a million iron wire telegraph post protectors leads him to uphold iron as entirely satisfactory. So, on this one point, as well as on the necessity existing for a good earth, a portion of the practical and theoretical camps have been able to agree."

A memorable discovery was made in 1786, by Luigi Galvani,* professor of Anatomy in the University of

* It is a curious fact that much difference of opinion existed in scientific literature of the time of Galvani concerning the light in which he himself viewed his discovery. That Galvani knew the effects which electricity produced in animal organisms there can be no doubt, for he had long before experimented with the effects of electrical discharges on such organisms. When he saw the convulsive movements of the frog's legs produced, as he thought entirely without the intervention of any electrical discharge, he imagined that he had discovered, not a new electric source outside the frog's legs, but either a true vital fluid, or, as he afterwards appeared to believe, an electric source within the frog; i. e., that the frog preparation was itself an electric source, and this, as we know, is true. The great discovery that the combination of metals outside the frog formed a true electric source, was afterwards made by Volta and not by Galvani.

In a "Supplement to the Encyclopædia, or Dictionary of Arts, Sciences, and Miscellaneous Literature," published in Philadelphia in 1803, the following description is given under the head "Galvanism" on page 73, of Vol. II, of the Supplement; viz.,

"GALVANISM, is the name now commonly given to the influence discovered nearly eight years ago by the celebrated Galvani, professor of Anatomy at Bologna, and which, by him and some other authors, has been called *animal electricity*. We prefer the former name, because we think it is by no means proved, that the phenomena discovered by Galvani depend either upon the electric fluid, or upon any law of animal life. While that is the

Bologna. Galvani was engaged in a series of observations as to the effects of atmospheric electricity on animal organisms, and had employed the hind legs of recently killed frogs as sensitive electroscopes. He

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case, it is surely better to distinguish a new branch of science by the name of the inventor, than to give it an appellation which probably may, and, in our opinion, certainly does, lead to an erroneous theory."

"M. Galvani was engaged in a set of experiments, the object of which was to demonstrate, if possible, the dependence of muscular motion upon electricity. In the course of this investigation, he had met with several new and striking appearances which were certainly electrical; soon after which, a fortunate accident led to the discovery of the phenomena which constitute the chief subject of this article. The strong resemblance which these bore to the electrical facts which he had before observed, led almost irresistibly to the conclusion that they all depended on the same cause. This opinion he immediately adopted; and his subsequent experiments and reasonings were naturally directed to support it. The splendor of this discovery dazzled the imaginations of those who prosecuted the enquiry; and for some time his theory, in so far at least as it attributed the whole to the agency of the electric fluid, was sanctioned by universal approbation. Of late, however, this opinion has rather lost ground; and there are now many philosophers who consider the phenomena as totally unconnected with electricity."

"We propose, in the *first* place, to enumerate the chief facts which have been ascertained on the subject; we shall then enquire, whether or not the cause of the appearances be the electric fluid; and, *thirdly*, we shall examine how far it has been proved, that this cause is necessarily connected with animal life."

"Whilst Galvani was one day employed in dissecting a frog, in a room where some of his friends were amusing themselves with electrical experiments, one of them having happened to draw a spark from the conductor at the same time that the professor noticed, that when the nerves of such preparations were connected with the muscles of the leg by means of metallic conductors, that the legs were violently convulsed.

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touched one of the nerves of the animal, its whole body was instantly shaken by a violent convulsion. Astonished at the phenomenon, and at first imagining that it might be owing to his having wounded the nerve, he pricked it with the point of his knife, to assure himself whether or not this was the case, but no motion of the frog's body was produced. He now touched the nerve with the instrument as at first, and directed a spark to be taken at the same time from the machine, on which the contractions were renewed. Upon a third trial, the animal remained motionless; but observing that he held his knife by the handle, which was made of ivory, he changed it for a metallic one, and immediately the movements took place, which never was the case when he used an electric substance."

"After having made a great number of similar experiments with the electrical machine, he resolved to prosecute the subject with atmospheric electricity. With this view he raised a conductor on the roof of his house from which he brought an iron wire into his room. To this he attached metal conductors, connected with the nerves of the animals destined to be the subject of his experiments; and to their legs he fastened wires which reached the floor. These experiments were not confined to frogs alone. Different animals, both of cold and warm blood, were subjected to them; and in all of them considerable movements were excited whenever it lightned. These preceded thunder, and corresponded with its intensity and repetition; and even when no lightning appeared, the movements took place when any stormy cloud passed over the apparatus. That all these appearances were produced by the electric fluid, was obvious."

"Having soon after this suspended some frogs from the iron palisades which surrounded his garden, by means of metallic hooks fixed in the spines of their backs, he observed that their muscles contracted frequently and involuntarily as if from a

Galvani had long been searching for the presence of a vital force or fluid which could be assigned as the cause of vitality; and, when he saw the movements of

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shock of electricity. Not doubting that the contractions depended on the electric fluid, he at first suspected that they were connected with changes in the state of the atmosphere. He soon found, however, that this was not the case; and having varied, in many different ways, the circumstances in which the frogs were placed, he at length discovered that he could produce the movements at pleasure by touching the animal with two different metals, which, at the same time, touched one another either immediately or by the intervention of some other substance capable of conducting electricity."

"All the experiments that have yet been made may be reduced to the following, which will give the otherwise uninformed reader a precise notion of the subject."

"Lay bare about an inch of a great nerve, leading to any limb or muscle. Let that end of the bared part which is farthest from the limb be in close contact with a bit of zinc. Touch the zinc with a bit of silver, while another part of the silver touches, either the naked nerve, if not dry, or, whether it be dry or not, the limb or muscle to which it leads. Violent contractions are produced in the limb or muscle, but not in any muscle on the other side of the zinc."

"Or, touch the bared nerve with a piece of zinc, and touch, with a piece of silver, either the bared nerve, or the limb; no convulsion is observed, till the zinc and silver are also made to touch each other."

"A fact so new, illustrated by many experiments and much ingenious reasoning, which Professor Galvani soon published, could not fail to attract the attention of the physiologists all over Europe; and the result of a vast number of experiments, equally cruel and surprising, has been from time to time laid before the public by Valli, Fowler, Monro, Volta, Humboldt, and others."

the frog's legs he thought he had discovered the true vital fluid. Galvani's observations produced an excitement throughout the scientific world fully equal to that produced by the invention of the Leyden jar, and his experiments were repeated by acute observers in all parts of the scientific world.

Among other investigators in this field was Alexander Volta. At first he accepted Galvani's explanation as to the cause of the phenomena observed in the frog's leg, but soon afterwards he came to the conclusion that what Galvani had actually discovered was not the cause of vitality, but a new method of producing electricity.

Volta conducted an extended series of investigations which in 1796 resulted in the invention of the voltaic pile.* This invention may generally be regarded as

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* In a letter in French to Sir Joseph Banks read by the latter to the Royal Society on the 26th of June, 1800, Volta thus described, in Transactions of the Royal Society for the year 1800, on p. 403, his great discovery of the pile and I append a translation of parts of the above.

A Come en Milanois, ce 20me Mars, 1800.

"Après un long silence, dont je ne chercherai pas à m'excuser, j'ai le plaisir de vous communiquer, Monsieur, et par votre moyen à la Société Royale, quelques resultats frappants auxquels je suis arrivé, en poursuivant mes expériences sur l'électricité excitée par le simple contact mutuel des métaux de différente espèce, et même par celui des autres conducteurs, aussi différents entr'eux, soit liquides, soit contenant quelque humeur, à laquelle ils doivent proprement leur pouvoir conducteur. Le principal one of the most important ever made in electrical science.

Volta's invention of the electric pile belongs to the

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de ces resultats, et qui comprend à-peu-près tous les autres, est la construction d'un appareil qui ressemble pour les effets, c'est-à-dire, pour les commotions qu'il est capable de faire éprouver dans les bras, &c. aux bouteilles de Leyde, et mieux encore aux batteries électriques foiblement chargées, qui agiroient cependant sans cesse, ou dont la charge, après chaque explosion, se rétabliroit d'elle-même ; qui jouiroit, en un mot, d'une charge indéfectible, d'une action sur le fluide électrique, ou impulsion, perpétuelle ;"

"Je vais vous donner ici une description plus détaillée de cet appareil."

"Je me fournis de quelques douzaines de petites plaques rondes ou disques, de cuivre, de laiton, or mieux d'argent, d'un pouce de diamétre, plus ou moins, (par exemple, de monnoyes,) et d'un nombre égal de plaques d'étain, ou, ce qui est beaucoup mieux, de zinc, de la même figure et grandeur, à-peu-pres ; je dis à-peu-près, parcequ'une précision n'est point requise, et, en général, la grandeur, aussi bien que la figure, des pièces métalliques, est arbitraire : on doit avoir égard seulment qu'on puisse les arranger commodément les unes sur les autres, en forme de colonne. Je prépare en outre, un nombre assez grand de rouelles de carton, de peau, ou de quelque autre matière spongieuse, capable d'imbiber et de retenir beaucoup de l'eau, ou de l'humeur dont il faudra, pour le succès des expériences, qu'elles soient bien trempées. Ces tranches ou rouelles, que j'appelerai disques mouillés, je les fais un peu plus petites que les disques ou plateaux métalliques, afin qu'interposées à ceux, de la manière que je dirai tantôt, ils n'en débordent pas."

"Ayant sous ma main toutes ces pièces, en bon état, c'est-à-dire, les disques métalliques bien propres et secs, et les autres non-métalliques bien imbibés d'eau simple, ou, ce qui est beaucoup mieux, d'eau salée, et essuyés ensuite légèrement, pour que l'humeur n'en dégoutte pas, je n'ai plus qu'à les arranger comme il convient ; et cet arrangement est simple et facile."

third class of great ideas or inventions; namely, that of fruitful inventions, because mature and timely.

Volta, however, was so far in advance of his co-

"Je pose donc horizontalement sur une table ou base quelque conque, un des plateaux métalliques, par exemple, un d'argent, et sur ce premier j'en adapte un second de zinc; sur ce second je couche un des disques mouillés; puis un autre plateau d'argent, suivi immédiatement d'un autre de zinc, auquel je fais succéder encore un disque mouillé. Je continue ainsi, de la même façon, accouplant un plateau d'argent avec un de zinc, et toûjours dans le même sens, c'est-à-dire, toujours l'argent dessous et le zinc dessus, ou *vice versâ*, selon que j'ai commencé, et interposant à chacun de ces couples, un disque mouillé; je continue, dis-je, à former, de plusieurs de ces étages, une colonne aussi haute qu'elle peut se soutenir sans s'écrouler."

"After a long silence, for which I do not attempt to excuse myself, I have the pleasure, Sir, to communicate to you, and through you to the Royal Society, some striking results which I have just obtained, in carrying on my experiments on the electricity excited by the simple, mutual contact of different kinds of metals, and even by that of other conductors, sufficiently different from one another, either liquids or substances containing some moisture, to which strictly speaking they owe their conducting powers. The principal of these results, which includes nearly all the others, is the construction of an apparatus which resembles so far as its effects are concerned, that is by the commotion which it is capable of making one feel in the arms, &c. the Leyden batteries, and still more the fully charged electric batteries. It acts, however, without ceasing, and its charge re-establishes itself after each explosion. It operates, in a word, by an indestructible charge, by a perpetual action or impulse on the electric fluid."

"I will here give you a detailed description of this apparatus."

"I obtain several dozen small round plates or discs of copper, brass, or better of silver, of an inch in diameter more or less, "for example coins," and an equal number of plates of tin or what is still better of zinc of the same shape and size approximately; I laborers, that he occupies the peculiar position of having no rivals for this invention; at least, I believe this is the case.

say approximately, because precision is not requisite; in general, the size as well as the figure of the metal pieces is arbitrary; we should have care only that we can conveniently arrange them one over the other in the form of a column. I prepare besides a sufficiently great number of discs of card-board, of cloth, or of some other spongy material, capable of imbibing and retaining considerable water or other liquid; for, it is necessary for the success of the experiment that they should be well moistened. These sections or discs, which I will call moistened discs, are made slightly smaller than the metal discs in order that they may be interposed between the other discs without projecting beyond them."

"Having these pieces conveniently arranged, and in good condition, that is to say the metal discs clean and dry, and the non-metallic discs sufficiently moistened with water, or what is still better salt water, they are then lightly pressed in order to prevent the liquid from running out. I have then only to arrange them as desired and this arrangement is simple and easy.

I place, generally horizontally, on a table or other base one of the metallic plates, for example, one of silver; on this first, I then place a second of zinc; on this second, I place a moistened disc; then another plate of silver, followed immediately by another of zinc to which I can make succeed a moistened disc. I then continue in the same manner coupling a plate of silver with one of zinc, and always in the same direction, that is to say always the silver above the zinc below, or vice versâ, according as I have commenced, interposing between each of these discs a moistened disc; I continue I say to form by many of these sets a column sufficiently high that it may be able to stand upright."

The communication then goes on to describe the manner in which electrical effects can be obtained from this pile or battery by connecting the end plates to the electro-receptive device that is to receive its discharge.

With this new and ready means for producing electricity placed at the disposal of investigators, a host of valuable inventions and discoveries followed. For example, in 1800, Nicholson and Carlisle* made the im-

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*The following description is thus given by Nicholson in Vol. IV, of a serial publication entitled, "A Journal of Natural Philosophy, Chemistry, and the Arts" published in London in 1801, in a paper on an "Account of the New Electrical Apparatus of Sig. Alex. Volta, and Experiments performed with the Same." On page 182 in this article the following description is given of the decomposition of water :—

"In all these experiments it was observed, that the action of the instrument was freely transmitted through the usual conductors of electricity, but stopped by glass and other non-conductors. Very early in this course, the contacts being made sure by placing a drop of water upon the upper plate, Mr. Carlisle observed a disengagement of gas round the touching wire. This gas, though very minute in quantity, evidently seemed to me to have the smell afforded by hydrogen when the wire of communication was steel. This, with some other facts, led me to propose to break the circuit by the substitution of a tube of water between two wires. On the 2d of May we, therefore, inserted a brass wire through each of two corks inserted in a glass tube of half an inch internal diameter. The tube was filled with New river water, and the distance between the points of the wires in the water was one inch and three-quarters. This compound discharger was applied so that the external ends of its wire were in contact with the two extreme plates of a pile of thirty-six half crowns with the correspondent pieces of zinc and pasteboard. A fine stream of minute bubbles immediately began to flow from the point of the lower wire in the tube, which communicated with the silver, and the opposite point of the upper wire became tarnished, first deep orange, and then black. On reversing the tube, the gas came portant discovery that an electric current passed through a compound liquid decomposes the liquid. Employing a voltaic pile consisting of thirty-six English half crowns, alternating with as many discs of zinc and paste-board

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from the other point, which was now lowest, while the upper in its turn became tarnished and black. Reversing the tube again, the phenomena again changed their order. In this state the whole was left for two hours and a half. The upper wire gradually emitted whitish filmy clouds, which, towards the end of the process, became of a pea green colour, and hung in perpendicular threads from the extreme half inch of the wire, the water being rendered semi-opaque by what fell off, and in a great part lay, of a pale green, on the lower surface of the tube, which, in this disposition of the apparatus, was inclined about forty degrees to the horizon. The lower wire of three quarters of an inch long, constantly emitted gas, except when another circuit, or complete wire, was applied to the apparatus ; during which time the emission of gas was suspended. When this last mentioned wire was removed, the gas re-appeared as before, not instantly, but after the lapse of four beats of a half second clock standing in the room. The product of gas, during the whole two hours and a half, was two-thirtieths of a cubic inch. It was then mixed with an equal quantity of common air, and exploded by the application of a lighted waxed thread."

"It might seem almost unnecessary to have reversed the order of the pile in building up, as reversing the tube must have answered exactly the same purpose. We chose, however, to do this, and found that when the zinc was at the bottom, its effects were reversed, that is to say, the gas still came from the wire commnicating with the silver, &c."

"We had been led by our reasoning on the first appearance of hydrogen to expect a decomposition of the water; but it was with no little surprise we found the hydrogen extricated at the contact with one wire, while the oxigen fixed itself in combination with the other wire at the distance of almost two inches.

soaked in salt water, these experimenters showed that when the current from such a pile was passed through salt water, the water was decomposed and oxygen and hydrogen obtained in a free state.

Shortly following this discovery Sir Humphry Davy,*

This new fact still remains to be explained, and seems to point to some general law of the agency of electricity in chemical opertions. As the distance between the wires formed a striking feature in this result, it became desirable to ascertain whether it would take place to greater distances. When a tube three quarters of an inch in diameter, and thirty-six inches long, was made use of, the effect failed, though the very same wires, inserted into a shorter tube, operated very briskly. The solicitation of other objects of enquiry prevented trial being made of all the various intermediate distances; but from the general tenor of experiments, it appears to be established, that this decomposition is more effectual the less the distances between the wires, but that it ceases altogether when the wires come into contact."

*The magnificent discovery by Davy of the compound nature of the alkalies and the alkaline earths is discussed by him in one of the Bakerian Lectures read on the 19th of November, 1807, and published in Vol. 98, of the Philosophical Transactions of the Royal Society of London for 1808, on page 2 :—

"*On the Methods used for the Decomposition of the Fixed Alkalies.*"

"The researches I had made on the decomposition of acids, and of alkaline and earthy neutral compounds, proved that the powers of electrical decomposition were proportional to the strength of the opposite electricities in the circuit, and to the conducting power and degree of concentration of the materials employed."

"In the first attempts, that I made of the decomposition of the on the 6th of October, 1807, made the immortal dis-

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fixed alkalies, I acted upon aqueous solutions of potash and soda, saturated at common temperatures, by the highest electrical power I could command, and which was produced by a combination of VOLTAIC batteries belonging to the Royal Institution, containing 24 plates of copper and zinc of 12 inches square, 100 plates of 6 inches, and 150 of 4 inches square, charged with solutions of alum and nitrous acid ; but in these cases, though there was a high intensity of action, the water of the solutions alone was affected, and hydrogene and oxygene disengaged with the production of much heat and violent effervescence."

"The presence of water appearing thus to prevent any decomposition, I used potash in igneous fusion. By means of a stream of oxygene gas from a gasometer applied to the flame of a spirit lamp, which was thrown on a platina spoon containing potash, this alkali was kept for some minutes in a strong red heat, and in a state of perfect fluidity. The spoon was preserved in communication with the positive side of the battery of the power of 100 of 6 inches, highly charged; and the connection from the negative wire was made by a platina wire."

"By this arrangement some brilliant phenomena were produced. The potash appeared a conductor in a high degree, and as long as the communication was preserved, a most intense light was exhibited at the negative wire, and a column of flame, which seemed to be owing to the developement of combustible matter, arose from the point of contact."

"When the order was changed, so that the platina spoon was made negative, a vivid and constant light appeared at the opposite point: there was no effect of inflammation around it ; but aeriform globules, which inflamed in the atmosphere, rose through the potash."

"The platina, as might have been expected, was considerably acted upon ; and in the case where it had been negative, in the highest degree."

"The alkali was apparently dry in this experiment ; and it seemed probable that the inflammable matter arose from its decomposition. The residual potash was unaltered ; it contained covery of the compound nature of potassa, which had heretofore been regarded as an elementary substance.

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indeed a number of dark grey metallic particles, but these proved to be derived from the platina."

"I tried several experiments on the electrization of potash rendered fluid by heat, with the hopes of being able to collect the combustible matter, but without success; and I only attained my object, by employing electricity as the common agent for fusion and decomposition."

"Though potash, perfectly dried by ignition, is a non-conductor, yet it is rendered a conductor, by a very slight addition of moisture, which does not perceptibly destroy its aggregation; and in this state it readily fuses and decomposes by strong electrical powers."

"A small piece of pure potash, which had been exposed for a few seconds to the atmosphere, so as to give conducting power to the surface, was placed upon an insulated disc of platina, connected to the negative side of the battery of the power of 250 of 6 and 4, in a state of intense activity; and a platina wire, communicating with the positive side, was brought in contact with the upper surface of the alkali. The whole apparatus was in the open atmosphere."

"Under these circumstances a vivid action was soon observed to take place. The potash began to fuse at both its points of electrization. There was a violent effervescence at the upper surface; at the lower, or negative surface, there was no liberation of elastic fluid; but small globules having a high metallic lustre, and being precisely similar in visible characters to quicksilver, appeared, some of which burnt with explosion and bright flame, as soon as they were formed, and others remained, and were merely tarnished, and finally covered by a white film which formed on their surfaces."

"These globules, numerous experiments soon shewed to be the substance I was in search of, and a peculiar inflammable principle the basis of potash. I found that the platina was in no way connected with the result, except as the medium for exhibiting the electrical powers of decomposition; and a substance of the

Davy showed that potassa consists of a hitherto undis-

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same kind was produced when a piece of copper, silver, gold, plumbago, or even charcoal were employed for compleating the circuit."

"The phenomenon was independent of the presence of air; I found that it took place when the alkali was in a vacuum of an exhausted receiver."

"The substance was likewise produced from potash fused by means of a lamp, in glass tubes confined by mercury, and furnished with hermetically inserted platina wires by which the electrical action was transmitted. But this operation could not be carried on for any considerable time; the glass was rapidly dissolved by the action of the alkali, and this substance soon penetrated through the body of the tube."

"Soda, when acted upon in the same manner as potash, exhibited an analogous result; but the decomposition demanded greater intensity of action in the batteries, or the alkali was required to be in much thinner and smaller pieces. With the battery of 100 of 6 inches, in full activity I obtained good results from pieces of potash weighing from 40 to 70 grains, and of a thickness which made the distance of the electrified metallic surfaces nearly a quarter of an inch; but with a similar power it was impossible to produce the effects of decomposition on pieces of soda of more than 15 to 20 grains in weight, and that only when the distance between the wires was about $\frac{1}{8}$ or $\frac{1}{10}$ of an inch."

"The substance produced from potash remained fluid at the temperature of the atmosphere at the time of its production; that from soda, which was fluid in the degree of heat of the alkali during its formation, became solid on cooling, and appeared to have the lustre of silver."

"When the power of 250 was used, with a very high charge for the decomposition of soda, the globules often burnt at the moment of their formation, and sometimes violently exploded and separated into smaller globules, which flew with great velocity through the air in a state of vivid combustion, producing a beautiful effect of continued jets of fire."

covered metallic element, potassium, combined with oxygen, and, shortly afterwards, he extended this discovery and showed that nearly the entire crust of the earth, consisting of various earths and alkaline earths, is similarly formed of metallic elementary substances combined with oxygen or other substances.

The valuable discoveries following the production of the voltaic pile did not stop here. In 1809, by employing a powerful voltaic pile, formed of two thousand couples, Davy showed, at the Royal Institution in London for the first time on an extended scale, the intense light of the voltaic arc, which he established between two carbon sticks or electrodes.

Although the arc light thus produced was by no means the first arc light,* yet it was perhaps the first

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*The light of the voltaic arc was known long before this. The first knowledge of the fact that a brilliant light is produced at a break in the circuit of a sufficiently powerful voltaic pile was known very shortly after the discovery of the pile. In Vol. II., page 200, of a publication entitled: "The Collected Works of Sir Humphry Davy," in a paper on "The Outlines of Galvanism," the following statement is made :—

"When in a powerful battery (one for instance containing two hundred series) the communication, after being broken, is again rendered complete, by the contact of two perfect conductors, a flash, or spark of light is perceived, analogous to that produced by electricity. This spark, or flash, when the battery is most powerful, is capable of passing through a considerable stratum of air, and of inflaming mixtures of hydrogen and oxygen. When time that it was publicly exhibited in such a manner as to demonstrate its possibilities as an artificial illuminant; and from this time up to a comparatively recent

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the me'allic substances by which it is transmitted, are of very small volume, it is possessed of the power of igniting them; and of making them enter into combustion when in contact with oxygen."

I have experienced no little difficulty in tracing the early history of the first carbon arc obtained by the use of the voltaic pile. Nearly all writers ascribe such arc to the battery of two thousand couples of the Royal Institution, but, beyond any doubt, Davy and others had demonstrated the existence of the voltaic carbon arc before this date.

On page 211 of the same Vol., in a paper entitled "An Account of Some Experiments on Galvanic Electricity made in the Theatre of the Royal Institution" the following account is given:—

"The apparatus employed in these experiments was composed of 150 series of plates of copper and zinc of 4 inches square, and 50 of zinc and silver of the same size. The metals were carefully cemented into four boxes of wood in regular order, after the manner adopted by Mr. Cruickshank, and the fluid made use of was water combined with about 1/100 part of its weight of nitric acid."

"The shock taken from the batteries in combination by the moistened hands, was not so powerful but that it could be received without any permanently disagreeable effects. Charges were readily communicated by means of them to coated jars, and to a battery; but in this case the effects produced by the electricity were much less distinct than in the case of immediate application."

"When the circuit in the batteries was completed by means of period, many futile attempts were made to successfully employ it as an artificial illuminant. As we all know this problem has at last been successfully solved, and successful arc lighting is an established fact.

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small knobs of brass, the spark perceived was of a dazzling brightness, and in apparent diameter at least 1/8 of an inch. It was perceived only at the moment of the contact of the metals, and it was accompanied by a noise or snap."

"When instead of the metals, pieces of well-burned charcoal were employed, the spark was still larger and of a vivid whiteness, an evident combustion was produced, the charcoal remained red hot for some time after the contact and threw off bright corruscations."

"Four inches of steel wire 1/170 of an inch in diameter, on being placed in the circuit became intensely white hot at the point of connection, and burnt with great vividness being at the same time red throughout the whole of their extent."

"Tin, lead, and zinc, in thin shavings were fused and burnt at their points of contact in the circuit, with a vivid light and with a loud hissing noise. Zinc gave a blue flame, tin a purplish, and lead a yellow flame violet at the circumference."

"When copper leaf was employed it instantly inflamed at the edges with a green light and vivid sparks, and became red hot throughout the whole of its diameter when it did not exceed four inches."

"Silver leaf gave a vivid light, white in the centre and green towards the outline, with red sparks or corruscations. Platina in thin slips, when made to complete the circuit, became white hot, and entered into fusion, and gave scintillations at the edges ; but whether any part was converted into oxyde could not be accurately determined."

"When gold leaf, attached by gum-water to white paper was burned by the spark, the light was of a bright yellow and the noise comparatively loud ; the gold was converted into an oxyde of purplish brown colour, which firmly adhered to the paper, and by regulating the course of the spark by means of the communicating wire, letters and figures were traced by the combustion, which appeared semi-transparent when exposed to the light."

"When the galvano-electric spark was taken by means of two pieces of charcoal partially covered with cotton, the cotton was readily inflamed; whether in its simple state, or sprinkled over with resin or sulphur."

"Fulminating mercury and gunpowder were deflagrated by means of the communication of charcoal; and hydrogen and the compound of inflammable gases, were readily made to burn when simply in contact with the atmosphere and to detonate when mixed with oxygen."

"A few only of these results have any claim to originality. On the phenomena of the combustion of bodies by galvanism we have been already furnished with many striking experiments, by our own countrymen, and by the German and French philosophers. And after the path is once discovered in researches of this kind, to pursue it requires but little ability or exertion. An account of common facts, under new circumstances, particularly when they are accompanied by striking phenomena, can however never be wholly useless; and it sometimes gives a novel interest to the subject, and tends to awaken curiosity."

It would appear from Davy's remarks at the end of the above quotation that he does not claim to have first discovered the brilliant effects of the electric arc light. The arc produced by the voltaic pile of 2,000 couples of the Royal Institution was different from prior arcs merely in degree of splendor. The phenomenon itself had before been well known.

This experiment of Davy is thus referred to by George J. Singer on page 405, of his "Elements of Electricity and Electro-Chemistry," published in London in 1814.

"With a large apparatus employed at the Royal Institution, which extends to 2,000 pairs of four-inch plates, points of charcoal were brought within a thirtieth or fortieth of an inch of each other before any light was evolved; but when the points of charcoal had become intensely ignited, a stream of light continued to play between them when they were gradually withdrawn even to the distance of near four inches. The stream of light was in the form of an arch, broad in the middle and tapering towards the charcoal points; it was accompanied by intense heat, and immediately ignited any substance introduced into it; fragments of diamond, and points of plumbago disappeared, and seemed to evaporate, even when the experiment was made in an exhausted receiver; though they did not appear to have been fused. Thick platina wire melted rapidly, and fell in large globules; the saphire, quartz, magnesia, and lime, were distinctly fused.

In rarefied air, the discharge took place at a greater distance, and the beam of light was made to pass through an interval of six or seven inches."

Another description of this experiment is thus given on page 463 of Vol. 35, of the Philosophical Magazine, by Alexander Tilloch, published in London in 1810:

"In the concluding lecture at the Royal Institution, the large Voltaic apparatus, consisting of two thousand double plates of four inches square, was put into action for the first time. The effects of this combination, the largest that has ever been constructed, were, as might have been expected, of a very brilliant kind."

"The spark, the light of which was so intense as to resemble that of the sun, struck through some lines of air, and produced a discharge through the heated air of nearly three inches in length, and of a dazzling splendour. Several bodies which had not been fused before, were fused by this flame; the new metals discovered by Mr. Tennant, iridium, and the alloy of iridium and osmium. Zircon and alumina were likewise fused;—charcoal was made to evaporate, and plumbago appeared to fuse in vacuo. Charcoal was ignited to intense whiteness by it in oxymuriatic acid gas, and volatilized in it, but without effecting its decomposition. A large Leyden battery, containing 24 coated jars, was discharged by a momentary contact of the wires to a degree that required from 20 to 30 turns of Nairne's electrical machine of eight inches diameter. All the electrical phænomena of the passage of electricity to a distance; the discharge through a Torricellian vacuum; the attractions and repulsions of light bodies, were demonstrated in a distinct way by means of this apparatus. It may be hoped that the application of so powerful an instrument, and such easy methods of producing the most intense heat, will lead to some new facts in analytical science."

This battery of two thousand cells was the one with which Davy at a later date made his investigations as to the effects produced on the voltaic arc by means of a magnet. He thus describes the effect on page 407 of Vol. II. of the Philosophical Transactions for 1821:

"Mr. Pepys having had the goodness to charge the great battery of the London Institution, consisting of two thousand double plates of zinc and copper, with a mixture of 1168 parts of water, 108 parts of nitrous acid, and 25 parts of sulphuric acid, the poles were connected by charcoal, so as to make an arc, or column of electrical light, varying in length from one to four inches, according to the state of rarefaction of the atmosphere in which it was produced; and a powerful magnet being presented to this arc or column, having its pole at a very acute angle to it, the arc, or column, was attracted or repelled with a rotary motion, or made to revolve, by placing the poles in different positions, according to the same law as the electrified cylinders of platinum described in my last paper, being repelled when the negative pole was on the right hand by the north pole of the magnet, and attracted by the south pole, and *vice versa.*"

"It was proved by several experiments that the motion depended entirely upon the magnetism, and not upon the electrical inductive power of the magnet; for masses of soft iron, or of other metals, produce no effect. The electric arc or column of flame was more easily affected by the magnet, and its motion was more rapid when it passed through dense than through rarefied air; and in this case, the conducting medium or chain of æriform particles was much shorter."

"I tried to gain similar results with currents of common electricity sent through flame, and *in vacuo.* They were always affected by the magnet; but it is not possible to obtain so decided a result as with Voltaic electricity, because the magnet itself became electrical by induction, and that whether it was insulated, or connected with the ground."

But it would far exceed the limits of this little book to trace here the many unsuccessful efforts that were made to bring about a commercial introduction of the arc light. At various intervals in the progress of electric science, it was believed that the time had at last come for the successful solution of the problem. Public expectation was aroused and more or less extensive trials made, but the conditions were not all fulfilled and that inevitable failure resulted, which, must perforce, attend all attempts in which any single condition remains unfulfilled.

Many attempts were made to operate such lights by means of voltaic batteries. Mr. Grove, who was among the experimenters in this direction, gives the following summary of his experiments on page 210, of Vol. 50, of the Mechanics' Magazine, published in London in 1849:

"Mr. Grove made some experiments six years ago on the subject, and then on one occasion delivered a lecture at the London Institution, when the theatre was illuminated by the voltaic arc. In preparing the present lecture, he had made a rough calculation as to its expenses, and the matter appeared to him (though attended with many practical difficulties) to be hopeful and promising. By interposing a voltameter in the circuit while the arc was produced, the consumption in the battery could be calculated; for every chemical equivalent of hydrogen evolved in the voltameter an equivalent of zinc, of sulphuric acid, and one-third of an equivalent of nitric acid would be consumed in each cell of the battery. Supplying these data for calculation, and making proper allowance for the amount of water contained in the commercial acids, &c., the theoretical expense of a battery such as he was exhibiting (fifty cells of the nitric acid combination, each platinum plate two inches by four) would be about two shillings per hour."

"He had tested by the photometric method of equality of shadows the intensity of the light as compared with a common wax candle, and found that after the battery had been an hour at work, the voltaic light was to the candle as 1444 to 1. He did not take this comparison of intensities as an absolutely fair practical comparison, nor did he give the above as a practical calculation, but thought it would be safe if twice that expense, or four shillings per hour, were assumed; the actual expense of charging the battery for a given time of action bore this out. He showed the inferiority of central as compared with separate lights for street illumination; but for light-houses, particularly for an intermittent light at regular intervals, or for signal lights, the application appeared to him to be reasonably approximate, and for more general purposes, far from hopeless — the practical difficulties, though undoubtedly not small, being, in his opinion, by no means insurmountable."

In the same direction is the following description on page 271, Vol. 51 of the same magazine:

THE ELECTRIC LIGHT.

Paper read on the comparative cost of making various Voltaic Arrangements. By Mr. W. S. Ward.

"The author stated that a series of calculations founded on data, produced to the Chemical Section at Swansea, showed the efficient power of three generally-used forms of batteries known as Smee's, Daniell's, and Grove's, would be equal, when 100 pairs of Smee's, 55 pairs of Daniell's, or 34 pairs of Grove's were used, and that the expense of working such batteries as regards a standard of 60 grains of zinc in each cell per hour, would be about 6d., 7½d., and 8d., respectively."

"This communication led to conversations on the economy of the electric light and electro-magnetic engines, in which Dr. Faraday, Mr. Shaw, Mr. Hunt, Mr. Elkington, and other gentlemen joined. Dr. Faraday remarked on the imperfect character of electric light, and its inapplicability for purposes of general illumination; all objects appearing dark when the eye was embarrassed by the intensity of the electric arc. Mr. Shaw and Dr. Percy instanced the magneto-electric machines which are employed at Birmingham for electro-plating, in which the current cost of the motive power, viz., a steam engine to put the magneto-electric machine in action, was the only working cost. Mr. Elkington stated that they had never been induced to abandon the voltaic battery which they employed in their manufactory, finding it more economical than the magneto-electrical machine of which he was the patentee. He also stated the remarkable fact, that a few drops of the sulphuret of carbon added to the cyanide of silver in the decomposing cell, had the property of precipitating the silver perfectly bright, instead of being granulated so dead as it is when thrown down from the solution ordinarily employed."

Perhaps one of the ablest pioneers in the direction of the commercial introduction of the arc light was Staite. He invented a number of very creditable arc lamps, but necessarily failed of success on account of the non-existence of a sufficiently cheap electric source. The following interesting account of his experiments is quoted from page 411, of Vol. 54, of the Mechanics' Magazine:

"The public curiosity has been much excited to be made acquainted with the report of the committee who were appointed so far back as August to inquire into the adaptation of this light for general illumination. The Committee having terminated their labours, the 9th inst., was the first time the exhibition took place of the apparatus, constructed with a view of testing the self-sustaining power of the mechanical arrangement adapted for the continued development of the light, the sustaining power of the battery, and the cost of the whole. It was understood that the same experiments were gone through on this occasion as were required by the Committee, and parties in the room volunteered to keep accurate registers of the effects produced. The Company, among whom we recognized several members of the Committee, were invited for half-past three, shortly after which the battery was charged, and at four the light was set in action, it being understood that it was to burn for five hours and a quarter without interruption, that being the period at which the Committee had expressed themselves satisfied that it could be continued for any definite length of time. The Rev. St. Vincent Beechey of Worsley, took charge of the photometrical arrangement, by which the comparative power of the light was ascertained, and we observed Mr. Daniel Stone, jun., attending to the means adopted for measuring the electric power passing. The light continued to burn with increasing brilliancy from four o'clock to six, giving successively a light, adjudged equal, the first half-hour, to 200 candles ; at five, to 300 ; at half-past five, to 400 ; and so successively till the electric fluid came into its fullest action at half-past six ; when the light, by the instrument used,—which we heard had been borrowed for the purpose from Mr. Cleminshaw, of the gas-works,—developed the immense number of 700 candles ; which intensity of light was steadily kept up till the experiment concluded at a quarter-past-nine o'clock. By way of passing the time, and amusing the parties assembled, many of the experiments were given which had previously excited so much interest at the Town Hall ; and it being perfectly light at the commencement of the experiment, and the sun shining, gave the opportunity of bringing coloured prints from the influence of the direct sunbeam to that of the ray from the electric light, in which not the slightest difference of shade of colour could be observed. The light of each was then passed through the prism, which still further established their identity, as their point of junction could not be ascertained,—thus proving its immense value to the manufacturer and exhibitor of goods. The light was then attempted to be diffused over the room, by means of lens, generally used in French lighthouses, and known as the Fresnell Lens, from the name of its inventor ; but as the room was only some 120 feet long, and the Fresnell Lens is calculated to act on an area of a mile no effect was produced beyond enabling us to imagine the possibility of so adapting it. The mode adopted by the English, by means of a parabolic reflector, which condenses the light in one direction, was then exhibited; and certainly the effect produced was sufficient to make us believe the statement, that at Sunderland the Commissioners were able to read at a distance of more than three miles at sea. The time having arrived at which the exhibition had been intended to close, before the company separated, a portion of the solutions produced by the action of the battery were drawn off and precipitated before the company present, and a white powder produced, which was represented to be of a commercial value sufficient to pay the whole expense of producing the light or of that evening's amusement. Of course, in the absence of the Report of the Committee it would be impossible for us, merely attending in the capacity of spectators, to pledge ourselves for anything more than we saw—we do not presume to be any judges of the value of these residues, nor to the precise amount of light developed, but it certainly is a most extraordinary amount of light; and the parties in the room—and we are not alluding to Mr. Staite, or any one apparently connected with him—stated with confidence the amount of candles to which it was equal; but if this light can be maintained for anything like a reasonable cost, its power of distinguishing colours by night as well as by day, and total absence of any heat, or contamination of air, renders it one of the most useful inventions on record."

The ingenious reference to the commercial value of the products obtained by the chemical action in the battery are strikingly suggestive of the glowing accounts of certain primary batteries of our own days.

When the brilliant discoveries of Faraday in the domain of magneto-electric induction finally led to the production of the magneto-electric machine, it was again believed that the problem of a commercial electric light was solved.

A certain Mr. Paine created no little excitement in this direction. His plan appears to have been to employ a magneto-electric machine for the decomposition of water and to employ the gas so generated to produce the lime or oxyhydrogen light. Judging from the explanations given by the inventor of some of the details of his invention he failed signally, in many respects, to understand just what he was doing. I give these quotations rather fully, however, because they show the public interest in electric lighting at this early date.

The following accounts of Mr. Paine's discoveries are taken from Vol 54, page 68, of the Mechanics' Magazine :

"What we have seen enables us to say, not only that Mr. Paine has extorted from nature the secret of the artificial production of light at a nominal cost, but that he has got hold of the key which unlocks and enables him to command a new force of nature, which is soon to supersede most of the forces now employed—something which is destined to work a revolution both in science and art."

"The operation, as we saw it, was as clear and clinching a demonstration as we ever witnessed in the range of chemical science. There was a rapid and abundant evolution of gas from the water in the jar, with which nothing whatever communicated save two flat strips of copper and the small tube which terminated in the jet or burner, without any possible connection with anything between the jar and burner, save the spirits of turpentine contained in another smaller glass jar. The electric apparatus being put in motion, as soon as the air over the water had been expelled, and the exit was closed, the pressure over the water drove the gas rapidly through the spirits of turpentine, and the jet beyond it being lighted, burned freely and with a high illuminating power. A jet attached to the tube between the jar of water and of spirits of turpentine, was lighted, and we saw the unmistakeable form of hydrogen, scarcely visible by daylight. This pure hydrogen was the gas evolved from the water, and could not possibly have come from the turpentine, for the current was all the time flowing from the water *through* the spirits of turpentine—and how could the spirits of turpentine give an illuminating flame on one side and the invisible flame on the other ?"

"Here, then, whatever may be the agency exerted on the water, by or through the flat ribbons of copper, be it something or nothing—whether we understand it or do not understand it—water is first converted into hydrogen, or some invisible burning gas, and then, having passed through spirits of turpentine, into a gas of very luminous flame."

"So far as light is concerned, here it is, Mr. Paine produces it somehow, and does it abundantly. There is no rubbing this out, and it is unpardonable in the 'scientific men' who must have seen it, that they were unwilling to acknowledge it—that they omitted a portion of the demonstration, and so left the public to infer the power and agency of other causes to account for the effect!"

"We now come to the question of the cost. Mr. Paine showed us every part of his apparatus, including his peculiar *helices* and *electrode*, not shown to the scientific men before mentioned. We are not at liberty to explain to our readers the peculiarity of their construction; suffice it to say, they elucidated the subject much to our mind, and clothed the discovery with scientific interest superior to its economical and practical."

"The means by which Mr. Paine exerts an agency upon the water through the copper ribbons, is a sort of electro-magnetic condenser—an instrument different from those manufactured by the electro-magnetic instrument makers in this city, only in the interior construction of its revolving helices. It consists of two sets of larger permanent, horse-shoe magnets, parallel and opening in the same direction, between the poles of which a pair of helices are made to revolve horizontally. There is no galvanic action in the case, and no expense whatever on these helices but of the slight mechanical force which is necessary to give them a moderately rapid revolution, they meeting no resistance but that of a common pivot and the slight friction of their poles upon metallic discs to effect the successive discharges.† But the power of this simple arrangement to evolve electricity is tremendous.

† See foot note page 133.

The electrical force compared with the mechanical cause, is like that of the rush of water which carries the wheel of a great cotton factory compared with the effort of a child who may hoist the gate. At each discharge of the helices, and there are many in a second, according to the rapidity, an abundant crop of gas bubbles is produced: and this is owing partly to the peculiar construction of the electrode, or form of the poles where presented in proximity to each other in the water of the jar. This electrode is a point of great interest, and it is just at this point that the mighty and mysterious fluid, so potently commanded and propelled by helices, may prove too big for its business, and show its relationship to the favorite weapon of Jove. Here is a stupendous difficulty which has tasked the courage and inventive genius of Mr. Paine—a difficulty of which the public could not be aware, and which seems to account for much delay. He has tamed the thunderbolt in this delicate point, at least so far as to insure perfect safety with due care. Other safe-guards may yet be added. However, it is but right to say, that it would not be strange if carelessness and temerity should hereafter meet with a fate here—that would be a caution to them."

"The next question is, whether there is any expense of the spirits of turpentine. We certainly could not discover, while we watched it, the slightest waste or diminution. Mr. Paine, and others testify, that there is no expenditure of that material. The nature of the luminous flame convinced us that it had gained nothing in quantity, only something in quality, from the spirits of turpentine; and this hypothesis, as any booked-up chemist will admit, is nothing unprecedented. In "Stockhard's Chemistry," an excellent work, we find the following—page 473:

"Starch, as shown by these experiments, is converted by sulphuric acid, on moderate heating into gum; on stronger heating, into sugar. In the latter case, also, dextrine is first formed, but this soon passes over into sugar. Accordingly, sulphuric acid exerts two different actions. By the first action, the starch becomes gum (dextrine). By the second action, the dextrine becomes sugar."

"It has not yet been explained how this effect was produced. Starch, starch-gum, and starch-sugar have each the same constitution (isomeric,) so that their difference undoubtedly depends upon a different arrangement of the atoms of carbon, hydrogen, and oxygen contained in them, and it is undoubtedly the sulphuric acid which effects this change in the position of the atoms."

"Then, again; after a man has, with his own eyes, seen water converted into hydrogen, and nothing else—unless the oxygen goes off through the solid copper ribbon of the positive pole into a cup of water, and is there drowned without a sign or a bubble —we say, after a man has seen this transformation of water, so unauthorized by the books, it will not be very incredible to him that the spirits of turpentine may change the *quality*—the electrical state—arrangement of particles, or whatever you may suppose it—in the hydrogen, without imparting anything whatever to it. This, we must say, is what we are strongly inclined to believe that it does. On the whole, we feel confident that Mr. Paine has discovered the means of producing an inexpensive light of the purest and most efficient quality, and opened a new and vast field in science. We have seen for ourselves, and find that we have done Mr. Paine very great, though not intentional, injustice. And we can hardly find words to express our surprise at the Scientific Report, which was partly the cause of our doing so. The demonstration which Mr. Paine then presented could not have been of a doubtful character to *chemical* eyes. Those gentlemen must have understood and believed more than they reported."

So also on page 114 of the same volume:

"Mr. Paine commenced turning the wheel in the Magneto-Electric Machine, and we all looked to see the gas arise from the *electrodes* in the jar of water, but no gas appeared. At length Mr. Ames discovered that one of the wires or copper ribands had been detached, or had not been screwed on to the wire at the top of the bell-glass."

"This being corrected, Mr. Paine again commenced turning the machine, and instantly large bubbles of gas arose from the electrodes, and *filled the jar in less than a minute!* After taking out a stopper from the bell-glass, and allowing several jars-full of gas to escape, in order to expel the common air, and prevent an explosion, these were stopped, and the gas forced on through the gaspipe into the turpentine; and through this to the jet or burner. Between the jar of water where the gas was generated and the jar of turpentine, a jet issued from the pipe. This was lighted, and proved to be hydrogen gas. The flame, in front of a window, was so pale that it could not be perceived. We could see it by putting a dark body behind it. While this was burning, the gas was forced along through the turpentine to the other burner. A flame was applied to this, *and a brilliant light was shown!*"

"Here were two flames burning at the same time, from the same gas—the first, before passing through the turpentine, burned with a pale, almost imperceptible light,—the second, after passing through the turpentine, burning with a light superior to any gas that I ever saw before. When the magnetic machine was stopped, not a bubble of gas would appear in the jar, and the lights went out. This small machine generated gas enough to supply a dozen burners, any one of which I should think sufficient to light a room."

"Now, it will naturally be asked, 'could not this tremendous electrical power which decomposed the water, be obtained from some other source than the magnetic machine?' This question occurred to me before I saw the operation; and I determined, if possible, to satisfy myself upon the subject. I, therefore, with Mr. Paine's full permission, examined the table. I could easily see that no wires or pipes entered the glass jar of water, except the two connected with the magnetic machine. It was, therefore, to the magnetic machine that my attention was mainly directed. This machine I took up, and lifted it entirely away from the table—saw that no wires, pipes, or metallic substances whatever had any connection with it from the table. I placed the machine again on the table and turned the crank, and produced the gas in the jar, in the same manner and with the same success that Mr. Paine had done. Mr. Ames and Mr. Merrick did the same, and we were all satisfied; *perfectly* satisfied *that the water was decomposed by the electricity from the magnetic machine, and nowhere else.* To deny this, we must deny the evidence of our own senses. The gas was also produced faster, by a thousand, yes, ten thousand times, than we had ever seen it before by a similar apparatus! We had also the most positive evidence that the gas, after passing through turpentine, furnished a brilliant light. The gas produced *appeared* to be hydrogen—we judged by the smell and the burning; and yet *Mr. Paine said, although he called it hydrogen gas, it differed from the ordinary hydrogen.* I asked Mr. Paine why he interrupted the *positive pole* by the glass of water—why he cut this wire in two, and placed the ends in the glass of water? He said that unless this was done, both *hydrogen and oxygen* would be generated in the bell-glass; but that by this means he only obtained the hydrogen. There appeared to be no oxygen generated by the operation."

"As to the amount of turpentine consumed by passing the gas through it, it was impossible for us to determine in the short time—an hour; we were engaged in generating and burning the gas. Mr. Paine stated that the gas was not *carbonized*, but was *catalized* in passing through the turpentine, and there was no loss to the turpentine by the process.† Several gentlemen of high standing in Worcester, a few days previous to our visit, purchased at a store a small quantity of turpentine, measuring it accurately; which they took to Mr. Paine's establishment, and passed the gas, produced by three sets of magnets, through it for several hours, lighting the whole of Mr. Paine's house. The turpentine was again measured at the close, and found to have lost but a teaspoonful—only as much as would be lost by evaporation and by turning it from one vessel into another."

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†I have frequently met with equal ignorance of the laws of the conservation of energy during the past few years. In one instance a manufacturer was examining a 12-light dynamo electric arc machine with a view of introducing it into his works. He was especially desirous of knowing the power required to drive it. Applying his foot to the driving pulley, the machine being on open circuit, he had no difficulty in rotating it at a fairly high speed. He then remarked that he had a

† See foot-note page 134.

The discovery of the arc light though mature was unripe; for neither the proper lamps were invented, nor, what is more to the point, had efficient commercial means for developing electricity yet been produced.

It was not until the immortal Faraday conducted that magnificent line of experiments between 1831 and 1832, on the means for producing electricity directly from magnetism, that the road was opened for the production of a new electric source in the dynamo-electric machine.

It is interesting to note the manner in which several great inventions often go hand in hand, and how immature inventions that have long ago been made and forgotten, become ripened and called into active life by subsequent inventions that supply or fill out some points that the prior inventions lacked. For example, I have already called your attention to the fact that as soon as it was known that electricity transmitted

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small ½ horse power engine he used for small work, and did not doubt but that he could get the number of revolutions required from the engine in addition to the work for which he generally employed it, and when I assured him that he would need at least 10 horse power, or more, if he desired to run the machine for 15 arc lights, he was indignant that I should ask him to believe such a statement.

†An excellent illustration of the saying, so true in all domains of thought but especially so in the domains of scientific thought, "A little knowledge is a dangerous thing."

its effects practically instantaneously through conducting paths, inventors were not wanting to suggest such agent as a means for telegraphic communication between distant points. In such suggestions we find the germs of the modern telegraph.

But the invention of a feasible system of telegraphy was not possible until at least two other discoveries had been made; namely, that of the electro-magnet by Sturgeon in 1825, or by Henry* in 1830, and that by Daniell, in 1836, of a constant voltaic pile or battery.

The peculiarity in which Daniell's battery differed from others is to be found in the fact that it is capable of yielding for prolonged times an approximately constant or steady current.

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* The possibility of developing great magnetic power by the use of a small voltaic battery, is thus described by Prof. Henry on page 400, of Vol. 19 of Silliman's "American Journal of Science and Arts," for January, 1831;

"*On the application of the principle of the galvanic multiplier to electro-magnetic apparatus, and also to the developement of great magnetic power in soft Iron, with a small galvanic element; by Prof. Joseph Henry of the Albany Academy.*

"For a long time after the discovery of the principal facts in electro-magnetism, the experiments in this interesting department of science could be repeated only by those who were so fortunate as to possess a large and expensive galvanic apparatus. Mr. Sturgeon, of Woolwich, did much towards making the subject more generally known, by shewing that when powerful magnets are used, many of the most interesting experiments can be performed with a very small galvanic combination. His articles of apparatus, constructed on this principle, are of a much larger size, and more convenient, than any before used. They do not, however, form a complete set, as it is evident, that strong magnets cannot be applied to every article required, and particularly to those intended to exhibit the action of terrestrial magnetism on a galvanic wire, or the operation of two galvanic wires on each other."

"In a paper, published in the Transactions of the Albany Institute, June, 1828, I described some modifications of apparatus, intended to supply this deficiency of Mr. Sturgeon, by introducing the spiral coil on the principle of the galvanic multiplier of Prof. Schweiger, and this I think is applicable in every case where strong magnets cannot be used. The coil is formed by covering copper wire, from $\frac{1}{40}$ to $\frac{1}{20}$ of an inch in diameter, with silk; and in every case, which will permit, instead of using a single conducting wire, the effect is multiplied by introducing a coil of this wire, closely turned upon itself. This will be readily understood by an example: thus, in the experiment of Ampère, to shew the action of terrestrial magnetism on a galvanic current, instead of using a short single wire suspended on steel points; 60 feet of wire, covered with silk, are coiled so as to form a ring of about 20 inches in diameter, the several strands of which are bound together by wrapping a narrow silk ribbon around them. The copper and zinc of a pair of small galvanic plates are attached to the ends of the coil, and the whole suspended by a silk fibre, with the galvanic-element hanging in a tumbler of diluted acid. After a few oscillations, the apparatus never fails to place itself at right angles to the magnetic meridian. This article is nothing more than a modification of De la Rive's ring on a larger scale."

"Shortly after the publication mentioned, several other applications of the coil, besides those described in that paper, were made in order to increase the size of electro-mangnetic apparatus, and to diminish the necessary galvanic power. The most interesting of these, was its application to a developement of magnetism in soft iron, much more extensively, than to my knowledge has been previously effected by a small galvanic element."

"A round piece of iron, about $\frac{1}{4}$ of an inch in diameter, was bent into the usual form of a horse-shoe, and instead of loosely coiling around it a few feet of wire, as is usually described, it was tightly wound with 35 feet of wire, covered with silk, so as to form about 400 turns; a pair of small galvanic plates, which could be dipped into a tumbler of diluted acid, was soldered to the ends of the wire, and the whole mounted on a stand. With these small plates, the horse-shoe became much more powerfully magnetic, than another of the same size, and wound in the usual manner, by the application of a battery composed of 28 plates of copper and zinc, each 8 inches square. Another convenient form of this apparatus was contrived, by winding a straight bar of iron 9 inches long with 35 feet of wire, and supporting it horizontally on a small cup of copper containing a cylinder of zinc, when this cup, which served the double purpose of a stand and the galvanic element, was filled with dilute acid, the bar became a portable electro-magnetic magnet. These articles were exhibited to the Institute in March, 1829."

"The idea afterwards occurred to me, that a sufficient quantity of galvanism was furnished by the two small plates, to develope, by means of a coil, a much greater magnetic power in a larger piece of iron. To test this, a cylindrical bar of iron, $\frac{1}{2}$ an inch in diameter, and about 10 inches long, was bent into the form of a horse-shoe, and wound with 30 feet of wire; with a pair of plates containing only $2\frac{1}{2}$ square inches of zinc, it lifted 14 lbs. avoirdupois. At the same time, a very material improvement in the formation of the coil suggested itself to me, on reading a more detailed account of Prof. Schweiger's galvanometer, and which was also tested with complete success upon the same horse-shoe; it consisted in using several strands of wire, each covered with silk, instead of one;—agreeably to this construction, a second wire, of the same length as the first, was wound over it, and the ends soldered to the zinc and copper in such a manner that the galvanic current might circulate in the same direction in both, or, in other words, that the two wires might act as one; the effect by this addition was doubled, as the horse-shoe, with the same plates before used, now supported 28 lbs."

"With a pair of plates 4 inches by 6, it lifted 39 lbs., or more than 50 times its own weight."

"These experiments conclusively proved that a great developement of magnetism could be effected by a very small galvanic element, and also that the power of the coil was materially increased by multiplying the number of wires, without increasing the length of each.

"The multiplication of the wires, increases the power in two ways; first, by conducting a greater quantity of galvanism, and secondly, by giving it a more proper direction, for since the action of a galvanic current is directly at right angles to the axis of a magnetic needle, by using several shorter wires, we can wind one on each inch of the length of the bar to be magnetized, so that the magnetism of each inch will be developed, by a separate wire; in this way the action of each particular coil becomes very nearly at right angles to the axis of the bar, and consequently, the effect is, the greatest possible. This principle is of much greater importance when large bars are used. The advantage of a greater conducting power from using several wires might in a less degree be obtained by substituting for them one large wire of equal sectional area, but in this case the obliquity of the spiral would be much greater and consequently the magnetic action less; besides this, the effect appears to depend in some degree on the number of turns which is much increased by using a number of small wires."

"In order to determine to what extent the coil could be applied in developeing magnetism in soft iron; and also to ascertain, if possible, the most proper length of the wires to be used—"

"A series of experiments were instituted jointly by Dr. Philip Ten Eyck and myself. For this purpose 1060 feet (a little more than $\frac{1}{5}$ of a mile) of copper wire of the kind called bell wire, .045 ($\frac{45}{1000}$) of an inch in diameter, were stretched several times across the large room of the Academy."

"*Experiment 1.* A galvanic current from a single pair of plates of copper and zinc 2 inches square, was passed through the whole length of the wire, and the effect on a galvanometer noted;— From the mean of several observations, the deflection of the needle was 15°."

"*Experiment 2.* A current from the same plates was passed through half the above length (or 530 feet) of wire, the deflection in this instance was 21°."

In the Morse system of telegraphy as generally practiced in the United States, the receiving instruments are maintained on closed circuits, and the requisite electrical impulses are sent into the line by means of interruptions or breaks in the circuit obtained by the movements of a telegraphic key. Since the battery is practically on closed circuit for long intervals of time, and batteries liable to polarization would be impracticable for such uses, Daniell's invention of a constant voltaic battery overcame this objection, and, together with the production of the electro-magnet, rendered the telegraph a possibility commercially.

For the benefit of those unacquainted with the nature of the effect produced in a voltaic battery, by what is called polarization, it may be stated that during the action of a voltaic cell one of the plates tend to become covered with a film of hydrogen or other similar electro-positive substance, the effect of which is to set up an electro-motive force counter or contrary in direction to that produced by the cell when in proper action. The effect of this counter electro-motive force is to decrease the efficient current produced by the cell.

A cell which polarizes, gives its maximum current only for a few moments after it is first set up and its circuit is closed. In a very little while, the effects of polarization decrease the effective current, so that, if telegraphic electro-receptive devices were placed in the circuit of such a cell, so great a necessity would exist for their constant readjustment as would render any telegraphic system impracticable from a commercial stand-point.

Daniell's constant voltaic battery belongs to a class of instruments in which two fluid substances are employed as electrolytes. The fluid that surrounds the negative plate, where the objectionable hydrogen collects, is chemically of such a nature as to be able to remove the film of hydrogen by entering into chemical combination with it.

In Daniell's constant cell this is done in a novel manner, the negative plate, the copper, being surrounded by a solution of copper sulphate so that the hydrogen that tends to be liberated at the surface, enters into combination with the electro-negative radical of the copper sulphate and deposits a film of copper on the surface of the plate.

Daniell gives the following general description of his cell in a letter to Michael Faraday, which is quoted from the Philosophical Transactions for 1836, on page 95, of Vol. I, of the "Annals of Electricity," published in London, in 1837.

"In the construction of this battery, I have availed myself of the power of reducing the surface of the generating plates to a minimum, the effective surface of one of the amalgamated zinc rods being less than ten square inches, whilst the internal surface of the copper cylinder to which it is opposed is nearly 72 inches. My principal objects have been to remove out of the circuit the oxide of zinc, which has been proved to be so injurious to the action of the common battery, as fast as the solution is formed, and to absorb the hydrogen evolved upon the copper without the precipitation of any substance which might deteriorate the latter."

"The first is completely effected by the suspension of the rod in the interior membranous cell, into which the fresh acidulated

The invention of the electro-magnet is the outgrowth of the life work of two remarkable inventors; namely,

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water is allowed slowly to drop from a funnel suspended over it, and the aperture of which is adjusted for the purpose; whilst the heavier solution of the oxide is withdrawn from the bottom at an equal rate by the syphon tube. When both the exterior and interior cavities of the cell were charged with the same diluted acid, and connexion made between the zinc and copper by means of a fine platinum wire $\frac{1}{200}$th of an inch in diameter, I found that the wire became red hot, and that the wet membrane presented no obstruction to the passage of the current."

"The second object is attained by charging the exterior space surrounding the membrane with a saturated solution of sulphate of copper instead of diluted acid; upon completing the circuit the current passed freely through this solution; no hydrogen made its appearance upon the conducting plate, but a beautiful pink coating of pure copper was precipitated upon it, and thus perpetually renewed its surface."

"When the whole battery was properly arranged and charged in this manner, no evolution of gas took place from the generating or conducting plates, either before or after the connexions were complete; but when a voltameter was included in the circuit, its action was found to be very energetic. It was also much more steady and permanent than that of the ordinary battery; but still there was a gradual, but very slow decline, which I traced at length to the weakening of the saline solution by the precipitation of the copper, and the consequent decline of its conducting power."

"To obviate this defect, I suspended some solid sulphate of copper in small muslin bags, which just dipped below the surface of the solution in the cylinders: which gradually dissolving as the precipitation proceeded, kept it in a state of saturation. This expedient fully answered the purpose, and I found the current perfectly steady for six hours together. This arrangement I have since improved by placing the salt on a perforated colander of copper fixed to the upper collar.

of Oersted*, who in 1820 discovered the relation existing between the voltaic pile and electro-magnetism, and of

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* Prof. Oersted's discovery created great excitement in scientific circles. Davy thus communicated the discovery to the Royal Society of London in a letter read Nov. 16th, 1820, which I quote from page 217, of Vol. VI., of a publication called "The Collected Works of Sir Humphry Davy."

"ON THE MAGNETIC PHENOMENA PRODUCED BY ELECTRICITY. IN A LETTER TO W. H. WOLLASTON, M.D., F. R. S.

MY DEAR SIR,

The similarity of the laws of electrical and magnetic attraction has often impressed philosophers ; and many years ago in the progress of the discoveries made with the voltaic pile, some inquirers (particularly M. Ritter) attempted to establish the existence of an identity or intimate relation between these two powers ; but their views being generally obscure, or their experiments inaccurate, they were neglected ; the chemical and electrical phenomena exhibited by the wonderful combination of Volta, at that time almost entirely absorbed the attention of scientific men ; and the discovery of the fact of the true connection between electricity and magnetism, seems to have been reserved for M. Oersted, and for the present year.

"This discovery, from its importance, and unexpected nature, cannot fail to awaken a strong interest in the scientific world; and it opens a new field of inquiry into which many experimenters will undoubtedly enter : and where there are so many objects of research obvious, it is scarcely possible that similar facts should not be observed by different persons. The progress of science is, however, always promoted by a speedy publication of experiments ; hence, though it is probable that the phenomena which I have observed may have been discovered before, or at the same

Ampère†, who in the same year conducted that remarkable series of investigations concerning the mutual attractions and repulsions existing between circuits,

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time, in other parts of Europe, yet I shall not hesitate to communicate them to you, and through you to the Royal Society."

"I found, in repeating the experiments of M. Oersted with a voltaic apparatus of one hundred pairs of plates of four inches, that the south pole of a common magnetic needle (suspended in the usual way) placed under the communicating wire of platinum (the positive end of the apparatus being on the right hand) was strongly attracted by the wire, and remained in contact with it, so as entirely to alter the direction of the needle, and to overcome the magnetism of the earth. This I could only explain by supposing that the wire itself became magnetic during the passage of the electricity, through it, and direct experiments which I immediately made proved that this was the case. I threw some iron filings on a paper, and brought them near the communicating wire, when immediately they were attracted by the wire, and adhered to it in considerable quantities, forming a mass round it ten or twelve times the thickness of the wire : on breaking the communication, they instantly fell off, proving that the magnetic effect depended entirely on the passage of the electricity through the wire. I tried the same experiment on different parts of the wire, which was seven or eight feet in length, and about the twentieth of an inch in diameter, and I found that the iron filings were everywhere attracted by it ; and making the communication with wires between different parts of the battery, I found that iron filings were attracted, and the magnetic needle affected in every part of the circuit."

† The labors of Ampère are thus referred to by Silliman in his "Principles of Physics, or Natural Philosophy," on page 605.

"Immediately after the first announcement of Œrsted's discovery of the magnetic powers of a conjunctive wire, Ampère, one of the most renowned of the French Physicists (born 1755—died through which electrical currents are circulating, and propounded a theory for electro-magnetism, which led to the production of the electro-magnet.

The electro-magnetic telegraph belonged to the third type of inventions; namely, of ripe inventions, and, the electro-magnet and the Daniell's battery having

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1836), commenced a series of experiments (September, 1820) to determine the laws concerned in these curious phenomena. Of three principal hypothesis which he framed to this end, he finally accepted and demonstrated the following ; viz.

"*A magnet is composed of independent elements or molecules, which act as if a closed electric circuit existed within each of them : in other words, each of these magnetic molecules may be replaced by a conjunctive wire bent on itself, in which a constant current of electricity is maintained, as from a Voltaic circuit.*

"This hypothesis he maintained by singularly ingenious experiments, many of which were the direct suggestion of the hypothesis itself, and he brought all, by his power of mathematical analysis, into exact conformity with his theory. This theory recognises only such forces as are common to mechanical physics, and often called '*push and pull*' forces. These forces are mutual, and belong to all electric currents. In permanent magnets, the minute circular and parallel currents, pertaining, by this theory, to each magnetic molecule, all act at right angles to the magnetic axis or line of force. Hence, as in Œrsted's experiment, the magnetic needle strives to place itself at right angles to the path of the current on the conjunctive wire, it follows, that currents in the magnet seek a parallelism to that in the conjunctive wire. Granting this to be true, it follows, as a corollary from the premises,—

"*1st. That two free conducting wires must attract or repel each other, according to the direction of the currents in them.*

"*2d. That a conjunctive wire may be made in all respects to simulate a magnet.*"

been produced, we quite naturally find 1837 a memorable year in the history of telegraphy. A number of claimants appear for the honor of its first conception; among these are Morse* in America, Steinheil in Munich, and Wheatstone and Cooke in England.

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*Like other great inventions the telegraph was not created in a single day. For many years prior to the completion of the invention Morse pondered and contrived. He asserts that the germs of the invention were sown on board the packet ship Sully, while on a voyage from Havre to New York City. The vessel sailed from Havre, October 1st, 1832. During the voyage Morse made numerous sketches of the apparatus.

Morse gives the following account of his invention of the electro-magnetic telegraph, on page 48, of a publication called "The Telegraph in America. Its Founders, Promoters, and Noted Men," by James D. Reid, New York, Derby Brothers, 1879.

"Before the end of the voyage on the Sully the invention had the following attributes. My aim at the outset was simplicity of means, as well as results. Hence, I devised *a single circuit of conductors* from some generator of electricity. I planned a *system of signs*, consisting of dots or points, and spaces, to represent numerals, and two modes of causing the electricity to *mark or imprint* these signs upon a *strip or ribbon of paper*. One was by *chemical decomposition of a salt* which should discolor the paper; the other was by the *mechanical action of the electro-magnet*, operating upon the paper by *a lever*, charged at one extremity with a pen or pencil. I conceived the plan of moving the paper ribbon at a *regular rate*, by means of *clock-work machinery* to receive the signs. These processes, as well as the mathematically calculated signs, devised for and adapted to *recording*, were sketched in my sketch-book. I also drew in my sketch-book modes of interring

The telegraphic apparatus of the two last (Steinheil and Wheatstone) says Prof. J. D. Forbes in the 8th Edition of the "Ency. Brit. America," resembles in principle Oersted's and Gauss': that of the first (Morse) is entirely original, and consists in making a ribbon of paper move by clock-work whilst interrupted marks are impressed upon it by a pen, etc. * * * *.

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the conductors in tubes in the earth, and, soon after landing, planned and drew out the *method upon posts.* This was the general condition of the invention (with the exception of the plan upon posts) when I arrived in New York, on the 15th of November, 1832."

"In reflecting on the operations of electricity as a proposed agent in telegraphy, I was aware that its presence in a conductor of *moderate length* could be indicated in several ways. The physical effects in a shock ; the visible spark ; visible bubbles during decomposition, and marks left from decomposition ; its magnetic effects upon soft iron and steel ; and its calorific effects,—these were all well-known phenomena. Could any of these be made available for *recording*, and at a *great* distance ? If so, which of them seemed to promise the surest result of a *permanent record ?* Static electricity was quickly dismissed as too uncontrollable, and I directed my attention exclusively to the phenomena of dynamic electricity. The decomposition of a salt having a metallic basis would leave a mark upon paper or cloth. If a strip of paper or cloth were moistened with the salt, and were then simply *put in contact* with a conductor charged with electricity, would there be any effect upon the paper ? A magnetic effect is produced exterior to the charged conductor. Is there any salt or substance so sensitive as to be affected either by decomposition, or in any other way, by this magnetic influence, by *simple contact* with an electrically charged wire ? It was doubtful, but worth an experiment."

Again on page 63, of the same book, he says, "The telegraphs of Morse have the inestimable advantage, that they preserve a permanent record of the dispatch they convey."

I need not describe Morse's method to you. It consists, as you know, in the employment of an electro-magnet to the armature of which is attached a stylus or point that records on a fillet of paper drawn underneath it, a series of dots and dashes corresponding to the letters of the alphabet.

"Between the date, 1835, of the completion of the first instrument and 1837, the date of its more public exhibition, there was a very important addition to it, which I had already devised and provided against a foreshadowed exigency, to meet it if it should occur when the conductors were extended, not to a few hundred feet in length in a room, but to stations many miles distant. I was not ignorant of the possibility that the electro-magnet might be so enfeebled, when charged from a great distance, as to be inoperative for *direct* printing. This possibility was a subject of much thought and anxiety long previous to the year 1836, long previous to my acquaintance or consultations with my friend Prof. Gale on the subject, but I had then already conceived and drawn a plan for obviating it. The plan, however, was so simple that it scarcely needed a drawing to illustrate it; a few words sufficed to make it comprehended. If the magnet, say at twenty miles distant, became so enfeebled as to be enabled to print *directly*, it yet might have power sufficient to close and open another circuit of twenty miles farther, and so on until it reached the required station. This plan was often spoken of to friends previous to the year 1836, but early in January, 1836, after showing the original instrument in operation to my friend and colleague, Prof. Gale, I imparted to him this plan of a relay battery and magnet to resolve his doubts regarding the practicability of my producing magnetic power sufficient to write at a distance."

The first submarine cable was first successfully laid between Dover, England, and Cape Griz Nez, France, in 1851. The first Atlantic cable was laid between Newfoundland and Ireland by Cyrus W. Field, in 1858.*

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*The following description given of the first announcement made by Cyrus W. Field, of the successful laying of the first Atlantic cable, is taken from page 279, of "The Laying of the Cable, or the Ocean Telegraph," by John Mullaly, New York: D. Appleton & Co., 1858.

MR. FIELD MAKES THE FIRST ANNOUNCEMENT TO THE NEW WORLD THAT THE CABLE IS LAID.

"About eight o'clock on the evening of the 4th instant, while the Niagara was proceeding up Trinity Bay, and some seventeen or eighteen miles distant from the landing place, Mr. Field left the ship for the purpose of visiting the telegraph station, and if possible, of sending a despatch to the United States announcing the success of the enterprise. As the boat of the Porcupine was along-side, it was cheerfully placed at his disposal by Captain Otter, who had now undertaken to pilot the Niagara. Mr. Field immediately set out, and as the Gorgon was on her way to the Bay of Bull's Arm, at the head of which the cable was to be landed, he went on board that vessel, and his boat was taken in tow. Here he was warmly received by Captain Dayman and his officers, who were in the full enjoyment of success. It was near two o'clock in the morning before he arrived at the beach, and as it was quite dark, he had considerable difficulty in finding the path that led up to the station. There was no house in sight, and the whole scene was as dreary and as desolate as a wilderness at night could be. A silence as of the grave reigned over everything before him; while behind, at the distance of a mile, he could see the huge hull of the Niagara looming up indistinctly through the gloom of night, and the light of her lamps on her deck making the darkness still darker and blacker by the contrast. He entered the

Contrasting the telegraphic apparatus which has been devised since that of Morse in 1837, and that in use at the present day, we find an almost continuous record of marked progress.

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narrow road, and after a journey of what appeared to be twenty miles came in sight of the station, which stands about half a mile from the beach. There was, however, no sign of life there, and the house, in its stillness, seemed strangely in unison with everything around. It had a deserted appearance, as if it had long since ceased to be the habitation of man. In vain he looked for a door in the front; there was no entrance there; he looked up at the windows in the hope, perhaps, of being able to enter by that way, but the windows of the lower story were beyond his reach, and the house having been partly built on piles gave it the appearance of being raised on stilts. A detour of the establishment, however, led to the discovery of a door in the side, and through this he finally succeeded in effecting an entrance. The noise he made in getting in, it was natural to expect, would arouse the inmates, but there seemed to be either no inmates to arouse, or those inmates were not easily disturbed. He stopped for a moment to listen, and as he listened he heard the breathing of sleepers in an apartment near him. The door was immediately thrown open, and in a few seconds the sleepers were awake, wide awake, and opening their eyes wider and wider as the wonderful news fell upon their astonished and delighted ears. They could hardly believe the evidence of their senses, and were bewildered at what they heard. The cable laid! when but a few short weeks before they had received the news of disaster and defeat, and they had looked only to the far distant future for the accomplishment of the great work. The cable laid, and they unconscious of it—they who had waited and watched so many weary days and weeks for the ships they had begun to believe would never come. What! and they were now in the bay—those same ships—within a mile of them! can they be dreaming? Dreaming! no—what they have heard is true, all true, and there is the living witness before them."

"What do you want?" was the exclamation of the first who

From 1837 to the present day, the world has witnessed the wonderful inventions of duplex telegraphy, including both diplex, which consists in the simultaneous

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was awakened, as he endeavored to rub the sleep out of his eyes."

"I want you to get up," said Mr. Field," and help us take the cable ashore."

"To take the cable ashore!" re-echoed the others, who were now just awaking, and who heard the words with a dim, dreamy idea of their meaning—"To take the cable ashore?"

"Yes," said Mr. Field, "and we want you at once."

They were now thoroughly aroused, and directing Mr. Field to the bedrooms of the other sleepers—for there were four or five others in the house—they prepared themselves with all haste to assist in landing the cable. But the other inmates were already awake, and when Mr. Field made his appearance on the corridor which divides the sleeping apartments on each side of the house, he found them awaiting him in the lightest description of summer clothing. As they had neither pants, vests, coats, shoes nor stockings on, the curious will have no difficulty in discovering in what they were dressed. They were as amazed at seeing Mr. Field as if he were an apparition; and when they recovered themselves sufficiently to ask the meaning of such a strange visitation, they were thrown into another state of wonderment by what he related. When they learned all, they dressed, and prepared themselves for the work before them. Mr. Field found that the telegraph office would not be open till nine o'clock that morning, and that the operator of the New York, Newfoundland and London Telegraph was absent at the time. He also ascertained that the nearest station at which he could find an operator was fifteen miles distant, and that the only way of getting there was on foot. Now, fifteen miles in Newfoundland is about equal to twice that distance in a civilized country, and is a tolerably long walk; but it was something to be the bearer of such news to a whole continent, and so two of the young men willingly volunteered for the journey, bearing with them, for transmission to New York and the whole United States, the following despatch, which contained the first transmission of messages over the same wire in the same direction, and the contraplex, which consists of such simultaneous transmission of messages in opposite

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announcement of the successful accomplishment of the work, and the historical importance of which will justify its republication here :

"United States Steam Frigate Niagara,
Trinity Bay, Newfoundland, August 5, 1858.

To the Associated Press, New York :

The Atlantic Telegraph fleet sailed from Queenstown, Ireland, Saturday, July 17, met in mid-ocean, Wednesday, the 28th, made the splice at one P. M., Thursday, the 29th, and separated. The Agamemnon and Valorous bound to Valentia, Ireland, the Niagara and Gorgon for this place, where they arrived yesterday, and this morning the end of the cable will be landed. It is 1,696 nautical, or 1,950 statute miles from the telegraph house at the head of Valentia harbor to the telegraph house at the Bay of Bull's Arm, Trinity Bay, and for more than two-thirds of this distance the water is over two miles in depth."

"The cable has been put out from the Agamemnon at about the same speed as from the Niagara."

"The electrical signals sent and received through the whole cable are perfect."

"The machinery for paying out the cable worked in the most satisfactory manner, and it was not stopped for a single moment from the time the splice was made till we arrived here."

"Captain Hudson, Messrs. Everett and Woodhouse, the engineers, the electricians, officers of the ships, and, in fact, every man on board the telegraph fleet, have exerted themselves to the utmost to make the expedition successful, and by the blessing of Divine Providence it has succeeded."

"After the end of the cable is landed and connected with the land line of telegraph, and the Niagara has discharged some cargo belonging to the Telegraph Company, she will go to St. Johns for coal and water, and then proceed at once to New York."

"CYRUS W. FIELD."

directions. It has witnessed the invention of quadruplex telegraphy, or of the simultaneous transmission over the same wire of four separate and distinct messages, two in one direction, and the remaining two in the opposite direction; of multiple telegraphy, in which, as in the harmonic system of Gray, a number of messages, greater than four, are simultaneously transmitted over the same wire; or, as in the synchronous multiplex system of Delaney, as many as 72 separate and distinct messages have been successfully transmitted over the same wire, either all in one direction, or a number in one direction, and the remainder in the opposite direction.

It was unquestionably the classic investigations of Faraday, described along with other researches in his "Experimental Researches"* in the domain of magneto-electric induction, that gave to the world that most

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*Faraday's magnificent experimental researches in electricity are published in three volumes, and 29 series, with addenda in "Faraday's Experimental Researches in Electricity" Vol. I and II, London: Bernard Quaritch, 1839 and 1844 and Vol. IV, By Richard Taylor and William Francis, London: 1855.

In the preface to Vol. 1, Faraday speaks thus on page iii:

"I have been induced by various circumstances to collect in One Volume the Fourteen Series of Experimental Researches in Electricity, which have appeared in the Philosophical Transactions during the last seven years: the chief reason has been the wonderful and efficient electric source the modern dynamo-electric machine. The successful production of the modern type of dynamo machine probably found its first exponent in the completed Gramme machine. It was, probably mainly, this machine that gave that wonderful impetus to electric science which, beginning about 1874–75, has continued to the present day, and furnishes one of the best examples of remarkable progress along a particular line of science that the world has ever seen. To attempt to trace the history of the dynamo-electric machine would more than fully occupy the time generally assigned to a single lecture. Suffice it to say that the first machine of this type was invented by Faraday, and was described in a communication to the Royal Society read during the latter part of 1831.

Faraday modestly describes this remarkable invention merely as "A New Electrical Machine." Faraday's dynamo consisted essentially of a disk of copper about 12 inches in diameter, so mounted on an axis as to be capable of rotation between the opposite poles of a powerful permanent magnet. Two collecting brushes, resting respectively on the axis and on the circumference of the wheel, sufficed to carry off the current generated by

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desire to supply at a moderate price the whole of these papers, with an Index, to those who may desire to have them."

"The readers of the volume will, I hope, do me the justice to remember that it was not written as a *whole*, but in parts; the earlier portions rarely having any known relation at the time to those which might follow. If I had rewritten the work, I, per-means of the potential difference produced as the rotating disk cuts through the lines of magnetic force of the permanent magnet. In this way electric currents were produced for the first time from permanent magnets.

Shortly afterwards Dal Negro and Pixii constructed more powerful machines on similar principles, and from that time up to the present, numerous inventors have appeared who have produced dynamo-electric machines of greater or less merit; among these I will merely mention the names of Ritchie, Saxton, Clarke,

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haps, might have considerably varied the form, but should not have altered much of the real matter: it would not, however, then have been considered a faithful reprint or statement of the course and results of the whole investigation, which only I desired to supply."

"I may be allowed to express my great satisfaction at finding, that the different parts, written at intervals during seven years, harmonize so well as they do. There would have been nothing particular in this, if the parts had related only to matters well ascertained before any of them were written:—but as each professes to contain something of original discovery, or of correction of received views, it does not surprise even my partiality, that they should have the degree of consistency and apparent general accuracy which they seem to me to present."

There are probably few books in the extended literature of electricity, if indeed there be any, which will so well reward the student as a careful reading, and re-reading of this masterly production, and I earnestly recommend the volumes to all who have not yet read them, who wish to become thoroughly grounded in electric science.

Jacobi, Sturgeon, Wheatstone, Brett, Hiorth, Page, Holmes, Wilde, and finally, the well-known inventors of our own days,

Faraday built better than he knew. Could he see the many forms of dynamos, which are now, in all parts of the world, converting mechanical energy into electrical energy with wonderful efficiency, he would appreciate the almost immeasurable value of the gift he freely gave to the world.

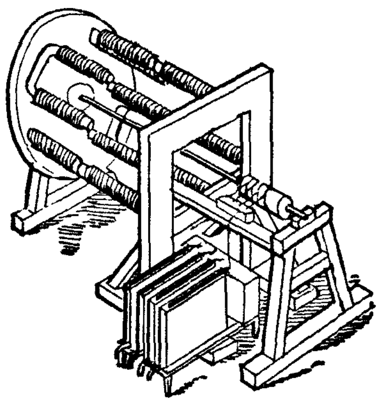
The cheap and reliable production of electricity on an extended scale, which was thus for the first time rendered possible by the successful invention of the dynamo, rendered many applications feasible on a commercial scale that had hitherto been limited to mere laboratory experiments. Prominent among these may be mentioned the use of the electric light for the purpose of artificial illumination on a commercial scale. The problem of successful arc lighting first was solved, and at present, in widely separated parts of the world, the day is extended far into the night by means of arc lights. Hundreds of thousands of arc lights, consuming miles and miles of carbon rods every night, show the wonderful development of this remarkable industrial outgrowth of Faraday's great discovery.

Then came the successful solution of the divisibility of the electric light by the invention of the incandescent lamp. It would be interesting, if time permitted, to give a brief account of the labors of the numerous able inventors whose life-work was required to finally produce the modern incandescent electric lamp. I would mention many distinguished names, but you are, however, well acquainted with them. I would tell you of the patient search for a suitable material for the incandescing filaments; of the various processes that were tried and rejected for preserving the filament from destruction; of the production of the enclosing all-glass lamp chamber; of the process for shaping the fibrous carbonizable material prior to its carbonization: of the care required in subjecting it to the carbonizing process; of the means necessary for ensuring uniformity in its light-producing power throughout all parts of its length; of the invention of the occluded-gas process, whereby a vacuum was permanently maintained in the lamp chamber, of the exhaustion and final sealing of the lamp chamber; and of the many other points, which appear insignificant in themselves, but which are, in reality, of vital importance to the production of a successful commercial incandescent electric lamp of long life and high efficiency. Suffice it to say that the incandescent electric lamp, like the arc light, is to-day a commercial success, and its continuance is assured, at least until replaced by something far better.

The invention of the modern dynamo electric machine rendered the extended commercial application possible of another invention made by numerous parties many years before. I allude to the invention of the electric motor, which, during the past few years has been successfully developed and put into actual use to an extent that appears almost incredible. Indeed, already, the various commercial applications of electricity as a motive power are such that it is doubtful if they do not already rival in extent the applications of electricity for the production of light.*

*To trace the early history of the electric motor would require a volume in itself, and that too, one of no mean dimensions. I shall, therefore, content myself in this connection, by the following description of the Jacobi and Page motors taken from pages 8 and 9 (3rd edition) of "The Electric Motor and its Applications," by Martin and Wetzler. New York: The W. J. Johnston Company, L't'd, 1892.

"Thanks to the substantial aid of the Emperor Nicholas of Russia, who contributed a sum of $12,000 to the work, Professor Jacobi, the discoverer of electro-plating, was enabled to prove in 1838, at St. Petersburg, on the Neva, that his electro magnetic motor of 1834, as improved, could replace the oarsmen in a boat



JACOBI MOTOR.

carrying a dozen passengers. Above is a perspective of the Jacobi motor of 1834, which was composed of two sets of electro-magnets. One set was fastened to the square frame *T*, disposed in a circle and with the poles projecting parallel with the axis. The other set *S* was similarly fastened to the disc *A* attached to

The first invention of the electric motor was very markedly the case of an unripe invention. Its successful commercial application necessarily failed for the want of some cheap means for producing the electric current required to drive it. Prior to the invention of the dynamo, the voltaic battery was the only available source for the production of large currents of electricity; but even the most efficient electric motor of the present day,

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the shaft and revolving with it. Each set comprised four magnets, and there were consequently eight magnetic poles. The current from a powerful battery passed through the commutator *C* to the coils of the electro-magnets, and as the magnets attracted each other the disc rotated. By means of the commutator on the shaft, the current was reversed eight times during each revolution, just as the poles of two sets of magnets arrived opposite each other. Attraction ceasing, repulsion took place, and the motion was thus accelerated. As the poles were alternately of different polarity, the reversals had the effect of causing attraction between each pole of one set and the next pole of the other. In his historic experiments of 1838, Jacobi used a modified form of this motor, so as to obtain greater power. In the new form, two sets of electro-magnets were attached to stationary vertical frames, one on each side of a rotating disc or star. Each set was composed of twelve electro-magnets. The electro-magnets on the rotating star were made in the form of bars passing entirely through the star. The axis carried a commutator formed of four wheels, regulating the direction of the current with the result that when the straight bar magnets were between two consecutive poles of the horse-shoe magnets on the frames, they were always attracted towards the one and repelled from the other. The reversal of the current took the place when the rotating poles were exactly opposite the fixed ones.

The following description of Page's motor is taken from page 19 of the same book:

"The most celebrated early motor next to that of Jacobi was driven by electricity so generated, could never hope to compete with the steam engine ; for, in order to produce currents by the voltaic pile it is necessary to burn zinc in some costly acid. Then, too, the number of heat units produced by the combustion of a pound of zinc is much smaller than the number produced by the combustion of a pound of carbon, the proportion being in about the ratio of 1,300 to 8,000. Until, therefore, zinc became cheaper than coal in a corresponding ratio, and sulphuric acid cheaper than ordinary air, the commercial use of the electric motor as driven by such means would of course be impracticable.

The early history of invention in the line of electric motors include a number of well known names, the most prominent of which, as I now recall them, are Ja-

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undoubtedly that of Professor C. G. Page of the Smithsonian Institute. This depended on a different principle from that of the others. When the end of a bar of iron was held near a hollow electro-magnetic coil or solenoid, the iron bar was attracted into the coil by a kind of sucking action until the bar had passed half way through the coil, after which no further motion took place. Professor Page constructed an electric engine on this principle about 1850. The solenoid was placed vertically, like the cylinder of an upright engine. A rod of iron, by way of armature, was fastened to a piston-rod connected to the crank of a shaft carrying a fly-wheel. The core moved downward by its weight, until its upper end was just leaving the solenoid, and thus one movement of the piston was accomplished. On passing the current the core or piston was attracted upward, and thus the second movement was completed. A commutating device was attached to the shaft which automatically admitted the current into the coil and cut it off at the right moment."

cobi, Page, Ritchie, Wilde, Dal Negro, and, coming down to the present day, the well known inventors whose successful electric motors are now occupying so important a field in various lines of work.

There is a circumstance connected with the operation of an electric motor to which I wish to call your attention, for it appears to show unquestionably that the electric motor is destined at an early date to occupy an even more extended field of usefulness than it does at present. This circumstance, briefly, is to be found in the fact that a properly constructed electric motor automatically regulates the amount of current that passes through its circuit in proportion to the load that is placed therein ; or, in other words, to the work that the motor is given to perform.

The self-regulating power of an electric motor is to be traced to the fact that, during its rotation when energized by the driving current, an electro-motive force is generated in its coils counter, or opposite in direction to, that which is applied to its terminals for the purpose of sending a driving current through it. This electro-motive force is called the counter electro-motive force of the motor. It tends to produce a current contrary in direction to that of the current which is passing through its coils and so decreases the amount of such current.

The counter electro-motive force produced by an electric motor during its rotation increases with the speed of rotation. Whenever, therefore, during the rotation of the motor, the amount of work which the machine has to perform is decreased and the motor tends to run at a higher speed, the counter electro-motive force is increased, and, consequently, the amount of current that is permitted to pass through the motor is correspondingly decreased. When, however, an increased load is put on the motor, and the machine thereby slows up, on this decrease in the rapidity of its rotation, the counter electro-motive force is decreased and consequently the amount of current which passes through the motor is correspondingly increased. In this way the current which drives the motor is automatically regulated with great nicety.

There is another reason why the future of the electric motor appears to be so bright. This is found in the high efficiency of the modern electric motor. Electric motors of an efficiency as high or even higher than 90 and 95 per cent. can be produced. Contrast this with the efficiency of the modern triple expansion steam engine, where an efficiency of 17 per cent. would be regarded as higher than, perhaps, the actual facts warrant. It would seem far from improbable, therefore, that the steam engine will, before long, become a thing of the past, and this will come as soon as some successful method is invented for producing electricity more cheaply than it can be produced by the intervention of a steam engine.

Indeed, even at the present time, electricity as a motor power is already successfully competing with steam in a number of cases. Examples of such successful competition are seen in cases where a reliable water power exists; for, in such cases, by the erection of a suitable water-wheel, the energy of the stream can be converted into electrical energy and this can be transmitted by wires or conductors over distances of many miles. A single prime motor, in the shape of a water-wheel can, in this manner, drive secondary motors at localities hundreds of miles distant.

Contrast the old method of driving secondary motors from a prime motor, by means of belting or gearing, with more recent means of transmitting electrical power through conductors, for distances of hundreds of miles and upwards, and you will see how great a rival steam power may soon expect to find in electric power. Look, for example, at that great problem of to-day, rapid transit by means of electricity, and see how efficient and satisfactory such systems for the propulsion of street railway cars have been found in almost every locality where they have been introduced.

But, in the meantime, let us not forget that most wonderful of modern discoveries which was made in 1861, by Philip Reis, of Germany. I know that it is not an entirely recognized fact that the telephone was invented by this gentleman; but, as I read the records of the past, I find, as I believe a majority of scientific men of the present day find, that Philip Reis did in reality invent this remarkable instrument. Whether this invention failed of commercial success, because it was immature or unripe, I will not now take the time to discuss, although I should be pleased to do so. Let it suffice to say that it was not until 1876 that Bell, of America, produced the first articulating telephone which was introduced into actual use on an extended commercial scale.

Like all other great inventions, the telephone has not been the product of a single mind. The inventions of many able minds were required to bring it to its present state of efficiency; and there can be no reasonable doubt that, were the competition greater, the instrument would be improved very far beyond its present achievements.

Looking at the telephone from a strictly scientific standpoint, it affords an admirable instance of the combined application of the three great inventions which we have just been discussing; namely, the dynamo-electric machine, the electric motor, and the long distance transmission of electric power.

A speaker talking into the receiving instrument of a magneto-electric telephone, at one end of a line wire or conductor, plays the part of a prime mover and furnishes, through the sound waves he originates, the mechanical energy required to move an iron diaphragm towards or from a magnet pole. The energy so supplied, like the energy supplied by a steam engine to a dynamo-electric machine, produces electric currents; for a magneto-electric telephone, when used as a transmitter is, in reality, a dynamo-electric machine driven by the voice of the speaker. The electric currents so produced are transmitted over a line wire or conductor, and, passing through the coils of a receiving instrument in the form of an electric motor, reproduces in its diaphragm motions exactly corresponding to those produced by the speaker's voice in the transmitting instrument. Consequently a person listening at the receiving instrument will hear all that is spoken into the transmitting instrument.

An outgrowth of the telephone appeared in the phonograph, the invention of Edison. In this instrument the speaker's voice, directed against an elastic diaphragm, causes a stylus or pen attached thereto to produce indentations on the surface of a sheet of tin-foil or other suitable surface, that is mechanically moved under the diaphragm. In order to reproduce this speech at any subsequent time a corresponding stylus, attached to a diaphragm, is given a to-and-fro motion by causing such stylus or point to be mechanically moved over the indented tin-foil surface. As this stylus climbs the hills and is pushed into the hollows of the record surface, it produces in the diaphragm of the receiving instrument motions precisely similar to those by which its impressions were made, and, consequently, causes such receiving diaphragm to reproduce the sounds uttered into the transmitting diaphragm.

An invention somewhat similar to the telephone is found in the instrument called the telephote, by means of which communication is carried on along rays of light instead of along conducting wires. But time presses, and I have yet to call your attention to many other remarkable inventions, of which I must, perforce, make but brief mention.

In 1821, Siebeck,* of Berlin, showed that electrical currents could be produced by the contact of dissimilar metals, whose ends were soldered together so as to form circuits, provided their junctions were maintained at a certain difference of temperature.

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* Siebeck's first experiment was made by using an electric circuit of a bar of bismuth and a bar of copper so soldered together as to form a hollow rectangle. When one of the junctions of such a circuit was heated a current of electricity was produced, the passage of which through the circuit was shown by the deflection of a magnetic needle supported inside the rectangle, so as to be free to move in a horizontal direction.

Siebeck showed that the direction of the electric current so produced depended on the junction that was heated. If it flowed in one direction when one of the junctions or solderings was heated, it flowed in the opposite direction when the other junction was heated. In the same manner the current produced by cooling either junction was in the opposite direction to that produced by heating that junction.

Siebeck proposed the name of thermo-electric currents for the electricity thus produced, and this name is

Although the discovery of thermo-electricity by Siebeck has never amounted to much commercially, yet this would reasonably appear to be in the near future, one of the directions along which the most marked progress is to be made in electric science.

In 1827, Dr. G. S. Ohm,* of Berlin, made a remarkable mathematical discovery, which is known in science as

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now generally accepted; he called the combination of the two metals or other substances necessary to produce the phenomena a thermo-electric couple, and the separate metals or substances, the thermo-electric elements. He found that very many metallic and non-metallic substances were capable of forming thermo-electric couples, and formed a thermo-electric series, arranged according to the order of their thermo-electric powers.

* Dr. Ohm published the results of his classic investigations in 1827, in a paper entitled "Die Galvanische Kette mathematisch bearbeitet von Dr. G. S. Ohm." "The Galvanic Current Mathematically Investigated by Dr. G. S. Ohm."

Probably no purely mathematical papers in the domain of electric science appeared during the time of Ohm, or, indeed, probably in any time, that contained so valuable a generalization as the fundamental principle concerning the laws of the electric circuit that Dr. Ohm thus first enunciated. Dr. Ohm's article is quite lengthy and forms a small volume in itself. I append a few quotations taken from a translation by Mr. William Francis in 1827, as published on page 416, of Vol. 2, of a publication entitled "Scientific Memoirs Selected from

Ohm's law. This law is generally expressed as follows: The current strength in any circuit is equal to the electro-motive force divided by the resistance; or, as you

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the Transactions of Foreign Academies of Science and Learned Societies" by Richard Taylor, London: 1841.

"*The force of the current in a galvanic circuit is directly as the sum of all the tensions, and inversely as the entire reduced length of the circuit*, bearing in mind that at present by reduced length is understood the sum of all the quotients obtained by dividing the actual lengths corresponding to the homogeneous parts by the product of the corresponding conductibilities and sections."

"From the equation determining the force of the current in a galvanic circuit in conjunction with the one previously found, by which the electric force at each place of the circuit is given, may be deduced with ease and certainty all the phenomena belonging to the galvanic circuit. The former I had already some time ago derived from manifoldly varied experiments with an apparatus which allows of an accuracy and certainty of measurement not suspected in this department; the latter expresses all the observations pertaining to it, which already exist in great number, with the greatest fidelity, which also continues where the equation leads to results no longer comprised in the circle of previously published experiments. Both proceed uninterruptedly hand in hand with nature, as I now hope to demonstrate by a short statement of their consequences; at the same time I shall consider it necessary to observe, that both equations refer to all possible galvanic circuits whose state is permanent, consequently they comprise the voltaic combination as a particular case, so that the theory of the pile needs no separate comment."

The reduced length referred to in the above quotation as the equivalent of the resistance of the circuit and is based on the character and dimensions of the substance forming the circuit.

And on page 422 of the same publication.

"All the electroscopic actions of a galvanic circuit of the kind, will find it mathematically in almost any electrical book you may chance to open, $C = \frac{E}{R}$.

This law is only true for continuous currents, as indeed Ohm suggests, another law being necessary to express similar relations in the case of alternating currents.

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described at the outset, have been above stated ; I therefore pass at present to the consideration of the current originating in the circuit, the nature of which, as explained above, is expressed at every place of the circuit by the equation

$$S = \frac{A}{L}.$$

Both the form of this equation, as well as the mode by which we arrive at it, show directly *that the magnitude of the current in such a galvanic circuit remains the same at all places of the circuit, and is solely dependent on the mode of separation of the electricity, so that it does not vary, even though the electric force at any place of the circuit be changed by abductive contact, or in any other way.* This equality of the current at all places of the circuit has been proved by the experiments of Becquerel, and its independency of the electric force at any determinate place of the circuit by those of G. Bischof. An abduction or adduction does not alter the current of the galvanic circuit so long as they only act immediately on a single place of the circuit ; but if two different places were acted upon contemporaneously, a second current would be formed, which would necessarily, according to circumstances, more or less change the first."

"The equation $$S = \frac{A}{L}$$

shows that the current of a galvanic circuit is subjected to a change, by each variation originating either in the magnitude of a tension or in the reduced length of a part, which latter is itself again determined, both by the actual length of the part, as well as by its conductibility and by its section."

Before closing this brief history of electrical invention I should call your attention to a notable application made by Jacobi* in 1831, in the direction of electrotyping, and a somewhat similar invention of electro-plating made at a later date by Elkington† in 1838, and somewhat later by Wright.‡

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* I believe that the first notice of Dr. Jacobi's discovery in England was the following communication sent to the Editor of the "Annals of Electricity" and published on page 507, of Vol. 3, by Mr. Julian Guggsworth.

"I have just learned that Professor Jacobi is occupying himself with a discovery which may, if in the end successful, prove of far more use than Daguerre's. He observed that the copper deposited by galvanic action on his plates of copper could, by certain precautions, be removed from those plates in perfect sheets which presented in relief, most accurately, every accidental indentation on the original plate. Following up this remark, he employed an engraved copper plate for his battery, caused the deposit to be formed on it, removed it by some means or other; he found that the engraving was printed thereon in relief (like a wood cut), and sharp enough to print from. Whether a repetition of the process from this galvanically formed block will furnish, in its turn, a copper plate from which impressions can be thrown off, is not yet established.

JULIAN GUGGSWORTH."

Wormwood Scrubs,
Feb. 5, 1839.

†The Messrs. Elkington took out a patent in connection with Mr. Q. W. Barrett for a process for electrolytically coating articles of copper and brass with zinc, on July 24, 1838.

‡Wright's inventions in electro-plating were based on

a fact published by Scheele, of the solubility of the oxide and cyanide of gold, silver and copper. I quote a passage from Scheele's Chemical Essays, pages 405 and 406, from p. 20 of that interesting book, "The Art of Electro-metallurgy" by G. Gore. D. Appleton & Co., New York, 1884:

'If, after these calces' [i. e. the cyanides of gold and silver] 'have been precipitated, a sufficient quantity of the precipitating liquor be added in order to redissolve them, the solution remains clear in the open air, and in this state the aerial acid [i. e. the carbonic acid], does not precipitate the metallic calx."

Continuing, Mr. Gore says:

"This statement suggested to Mr. Wright the probable suitability of the cyanides of gold and silver, dissolved in solutions of the alkaline cyanides, for the purpose of electro-plating; and he immediately took a solution, composed of chloride of silver dissolved in aqueous ferro-cyanide of potassium, and quickly obtained what had never been acquired before, viz. a *thick* deposit of *firm* and *white* silver by electrolytic action. In all previous trials the coating of silver had either been very thin, or in a state of dark-coloured, loose powder, completely useless for the intended purpose.

"The first article that received the successful coating was a small vase, and the next was a small figure of a kid. They were coated by Mr. Wright at his residence, and the process adopted was as follows:—A common, porous garden-pot, containing the silver solution, was placed in dilute sulphuric acid contained in an outer vessel; the article to be coated was immersed in the inner liquid, and connected by a wire with a cylinder of zinc surrounding the porous cell, and immersed in the dilute acid. It was about a month after this that a solution of actual cyanide (not ferro-cyanide) of silver and potassium was first employed by Mr. Wright for the same purpose. It is true that cyanides in several forms had been used both for electro-coppering and silvering about sixteen months previously; but that was by the simple immersion process, without the use of zinc, or a single cell or battery, and by that process no thick deposits can be obtained."

Jacobi called his process galvanoplasty,* but it is now generally known as electrotyping. By means of this process copies are made of various objects such as metals, or statues, in copper or other metals.

In the process of electro-plating an electric current passing through a bath containing a solution of a metallic salt decomposes said solution and dissolves a plate of metal hung at the anode, or electro-positive terminal of

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* A translation of Professor Jacobi's original paper on "Galvanoplastik; or the Process of Cohering Copper into Plates, or Other Given Forms, by Means of Galvanic Action on Copper Solutions. By Dr. M. Jacobi, Privy Councilor to the Emperor of Russia, and Member of the Royal Academy of Sciences,of St. Petersburg," appeared in p. 323 of Vol. 7, of the Annals of Electricity.

"The pages which I now submit to my readers contain such of my discoveries of the new application of the galvanic powers, as appear to be important with reference to practical and scientific individuals; and which, in some measure, already has become so. It happened, whilst I was in Dorpart, in the month of February, 1837, prosecuting my galvanic investigations, that I discovered a striking phenomenon which presented itself in my experiments, and furnished me with perfectly novel views. By an attentive observation and persevering pursuit of this phenomena, I soon became convinced that in this simple fact there lay a completely new field of interest; which by means of galvanic currents we might be able to arrive at successfully; but it was only by very gradual steps that I attained a knowledge of the simple conditions, on which the results are depending."

Also on page 495 of the same Volume:

"In the year 1837, whilst in Dorpart, I had a series of experiments to carry on, upon the strength and duration of galvanic the source, and deposits it in an adherent coating over any electrically conducting surface placed in the bath and connected to the kathode, or electro-negative terminal of the source. By making the plate hung at the anode of the same metal as that dissolved in the bath, the strength of the solution in the bath is maintained constant and the process becomes a continuous one, the metal being dissolved from the plate at the anode as rapidly as it is removed from the solution of the bath.

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currents produced by an apparatus constructed upon similar principles ; but instead of copper plates I furnished myself with copper cylinders, surrounded by animal bladders, for the purpose of keeping the liquids separate. As these bladders became damaged by use, they were taken out, and gave occasion to inquire into the form in which the copper was reduced. It was found on the surface of the copper cylinders, and in the inner folds of the bladders, partly in thin bars and partly in large and small corns of crystalline texture, which to those beneath shewed not the least attachment. Afterwards, however, whilst continuing to remove these corns, &c., it was found that they adhered more closely together, and required some force to separate them ; it was also found that the copper cylinder itself was completely covered with a layer of reduced copper, which, to my astonishment, was removed in large well-connected plates. As no mention had hitherto been made of such regular formations of reduced copper, these corns, &c., were held of a high interest. I must confess, indeed, that I was myself surprised, as I remarked at the time, that some fine file marks and indentations from hammer-blows, which were conspicuous on the surface of the copper cylinders, had, with the greatest degree of accuracy, given corresponding forms to the plates of reduced copper. This remarkable phenomenon was a strong proof of the conformation to the law by which copper is capable of being reduced, and which could not have been expected from the un-uniform productions which had previously

An important modern outgrowth of electro-plating, or more correctly of electrolysis, is to be found in the extremely valuable invention of the secondary or storage battery in 1859. The storage or secondary battery of Planté* consists essentially of plates of lead immersed in dilute sulphuric acid. By the passage of an electric current through the acid, electrolytic decomposition takes place, and, by a process called "forming the plates," which consists substantially in sending a current for a considerable length of time in one direction, and then

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been obtained. As the reduced plates acquire a certain degree of connection and firmness, there were hopes that, by a discernment of their management, these properties might be obtained in a still higher degree; and, finally, this humid method of forming copper plates on the surface of the cylinders, by galvanic action, immediately held out a practical result worthy of pursuing. How and by what manifold experiments these expectations shall be conformed with, and what will be acquired, in the course of performance, beyond that already done, cannot, in this place, be mentioned, where merely the description of the proceeding and the methods hitherto given are intended."

"It appears, therefore, that firm coherent copper may be reduced from its solution by the galvanic current. For this purpose we employ an apparatus similar to that formerly described."

* Planté published his original papers "Researches sur la polarization Voltaique" in the 49th vol. of the Comptes-rendus, page 402. The studies described in this paper were undertaken for the purpose of comparing the secondary currents produced by voltameters of different metals placed in different solutions. As a result of these and later investigations, he discovered the advantages

passing it through the cell in the opposite direction and repeating this change of direction many times, the lead plates become changed; one of them becomes finally coated with lead peroxide, and the other with finely divided metallic lead. If now, when in this state, the charging current be discontinued, the cell will act as an independent source of electric current, and will produce a current which will flow through the cell in the opposite direction to that of the current which was required to charge it.

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possessed by lead plates immersed in dilute sulphuric acid. He thus describes such a combination on page 14 of his book entitled "The Storage of Electric Energy." London: Whittaker & Co., 1887.

"Lead covered with peroxide of lead, in water acidulated by sulphuric acid, acts in fact in a manner exactly the reverse to that of zinc in the same liquid. It tends to decompose the water, by absorbing hydrogen, and to become the positive pole of a cell, if it is connected with lead not oxydised, whilst pure zinc tends to decompose the water, by absorbing oxygen, and becomes the negative pole of a cell in which it is opposed to another metal."

"To this cause of the development of a secondary current by the voltameter of lead electrodes, we may add the effect produced upon the wire or plate of the negative pole on short-circuiting the voltameter after being submitted to the primary current."

"The lead plate placed at the negative pole does not undergo, by the action of the primary current, as marked a change as that of the positive pole; nevertheless, as lead is always more or less oxydised by exposure to the air, it is brought to a more perfect metallic state by the hydrogen which is manifestly the means of reducing the cell, and its tint changes from a bluish grey to a much lighter grey."

During this discharge of the cell the lead peroxide $Pb O_2$ on one plate gives one of its atoms of oxygen and oxydizes the metallic lead on the other plate. When this oxydation becomes complete, both of the plates become covered with lead monoxide Pb O, and the cell ceases to furnish an electric current. If, however, the charging current be again sent through it, an atom of oxygen is again transferred from one plate to the other leaving the first plate as before covered with spongy lead and the other with lead peroxide of $Pb O_2$. By such a storage cell, a convenient means is provided for practically storing the energy of the electric current.

I have described the operation of charging the cell as consisting essentially in the transference of an atom of oxygen from one of the plates to the lead monoxide Pb O, on the other plate, whereby one of the plates becomes covered with spongy lead and the other with lead peroxide $Pb O_2$. In reality, this is but the final result, intermediate compounds being formed with which I will not burden you this evening.

I wish at this point to call your attention to the fact that a storage battery cannot any more properly be said to store electricity, than a music box can be said to store sound when mechanical power is applied to wind its driving spring. What the storage battery actually stores is the energy of the charging current. It acts as a device whereby energy is stored up by effecting chemical decomposition, such energy being transformed from mechanical energy to chemical potential energy. In discharging the storage battery this chemical potential energy becomes liberated and appears as electric energy, just as it does in the voltaic cell.

Planté's original battery was greatly improved by Faure in 1880, who, by spreading oxide of lead over the surface of the plates, greatly reduced the time required for forming the plates.

A very bright future is, in all probability, in store for the storage battery. Much, however, requires to be effected before it can take its place in the work of the world on a very extended scale. Considerable improvements, however, are being made in this direction, and, we may reasonably expect in the near future a better storage battery.

I have in this exceedingly brief and somewhat imperfect manner traced with you the progress made in electricity, from the time of the birth of the great idea of Thales until the present day. Although I know how dangerous it is even under the most favorable circumstances to assume the position of a prophet, yet I desire to venture a few suggestions concerning the great things that it seems to me electric science has in the near future for the human race. These to my mind are briefly as follows :—

(1.) A cheaper means for the production of electricity than is now possible by burning coal for the driving power of a steam engine, which in its part turns a dynamo-electric machine.

This invention will, probably, be found in some improvement in thermo-electricity, whereby coal will be burned directly to produce electricity, and not, as now, through the double intervention of a steam engine and dynamo.

(2.) The entire replacement of the steam engine by the electric motor.

I do not think it unreasonable to believe that many in my audience to-night will live to see the steam engine relegated to the scrap pile as antiquated, and, possibly, even to hear it spoken of in their times as an incredible instance of how an otherwise bright age should have remained satisfied for so long with such a clumsy contrivance for the conversion of energy.

(3). The successful solution of the problem of aerial navigation, effected, possibly, by means of the electric motor, and being rendered possible as a result of improvements in the economical production of electricity. To my mind this problem only needs for its successful solution, means for concentrating great power in small weight.

(4). The replacing of the electric light, that is the present electric light, with its preponderance of useless and injurious low heat rays, by some species of electrically produced light which shall possess a smaller proportion of the useless heat rays and a larger proportion of the desired light rays. Though this discovery may come by the discovery of some means of producing cold light by chemical phosphorescence, yet it seems more probable that it will be by means of physical phosphorescence, or by means of molecular bombardment as pointed out by Nikola Tesla in his classic experiments on the effects produced by alternating currents of extraordinary frequency and difference of potential.

(5). A more intelligent means than are now adopted in the therapeutical applications of electricity to the curing of diseases, whereby human life may be considerably prolonged, and human suffering lessened.

In concluding this very brief survey of the electric field I am reminded of a charming story that I remember reading in my early childhood. If you will pardon me I will relate the story as I remember it.

There once lived in the city of Bagdad a widow, who had an only son named Aladdin. Aladdin became the owner of a magic lamp which possessed the remarkable power of bringing to the aid of its owner the services of a powerful genie. No matter what service Aladdin wished, he had but to rub the lamp and the genie appeared, and gratified him. By its means he could hear the faintest whisper uttered thousands of miles away. By it he could annihilate time and distance, and be transferred, in the twinkling of an eye, to the tops of the highest mountains around Bagdad.

Do you not agree with me that Thales, at least potentially, rediscovered this wonderful talisman; for, when he rubbed the bit of amber, did he not call to the aid of the world the services of a genie more powerful than the slave of the lamp? Cannot the genius of electricity permit us to hear the faintest whisper uttered hundreds of miles away? Can we not by its means carry on communication with foreign lands under the bed of the ocean? Can we not by it annihilate time and distance? And if the genius of electricity has done so much for the world during the time that we have traced his works, does it seem that some of the things which I have pointed out to you as possibilities in the near future are not, after all, so extremely improbable?

Perhaps I may be pardoned if I add to the prophecies made at the close of the Brooklyn lecture in 1892, a subsequent prophecy, prepared for an article printed in the January number of this year's *McClure's Magazine* entitled "The Edge of the Future." It contains a brief statement of what appears to me may be expected in the future, and most of it in the not too distant future.

"In the nearer foreground I see a practical method for the production of electricity directly from the burning of coal. This achieved, there necessarily follows the universal adoption of the electric motor as a prime mover; the relegation of the steam-engine to the scrap-heap, and the almost immediate realization of the airship as a means of transportation.

"Assuming the cause of chemical affinity to lie in the unlike electric charges of the combining atoms, I see the practical realization of electric synthesis, whereby wholesome food-products will be directly formed under the potency of electric affinities. I see, too, a marked advance in electro-therapeutics, whereby human life will be prolonged and its sufferings alleviated. Diagnosis and prognosis will be profoundly aided by exact electrical measurements of the various organs of the human body as regards their electromotive force and resistance. The electro-therapeutist of the future will employ electric charges and currents for restoring the normal charges and currents of the body, as well as for the stimulation of nervous or muscular tissues.

"Back of these achievements I discern a practical apparatus for seeing through a wire—i.e., a device for looking into a receiver at one end of a metallic wire and seeing therein a faithful reproduction of whatever optical images are impressed on a transmitter at the other end—even though thousands of miles intervene. I see the possible use of the step-down transformer for the preparation of a road-bed or road-surface by the vitrification, *in situ*, of clay or other suitable soil, by the intense heating power of enormous currents of electricity.

"These things I believe I see with fair distinctness. In the further background I faintly see, dimly outlined through the clouds, an apparatus for the automatic registration of unwritten, unspoken thought, and its accurate reproduction at any indefinite time afterwards."

THE END.

APPENDIX.

Note.—There can be no doubt but that Gilbert's success in the domain of electricity was due largely to his methods, which, to a great extent, were those formulated by Bacon.

Credit has very properly been awarded to Bacon for the services he thus rendered physical science by the clear manner in which he pointed out the method that should be adopted by the scientific investigator; viz., the persistent, intelligent interrogation of nature as opposed to pure speculation. A danger exists, however, in going too far in the amount of such credit.

From the preceding quotation from the "Library of Useful Knowledge," on Bacon's "Novum Organon Scientiarum," one might well imagine that there had been no line of investigation of nature up to this time. Such, however, was far from being true. The methods of scientific investigation have been pretty much the same in all ages. Bacon by no means pointed out an entirely new road leading to the Mysteries of the Temple of Nature. It is true there were no well-defined, beaten broad-ways. Its travellers had been too few. There was only here and there a straggler who had wandered far into the hitherto unexplored land, and so few had followed his hesitating and uncertain footsteps that time had almost obliterated them. No wonder, therefore, that to many it seemed that Bacon was pointing out an entirely new way, and even to the present day he is given, I think, too much praise. I quite agree with Prof. Oliver Lodge, who thus refers to the matter in a very able book entitled "The Pioneers of Science" (London, Macmillan & Company, 1893, pp. 404). He is speaking of those great pioneers in science who, early in the dawn of true science, followed paths that are now broad and high ways.

The quotation is to be found on page 141.

"Of Lord Bacon, who flourished about the same time (a little later), it is necessary to say something, because many persons are under the impression that to him and his *Novum Organon* the reawakening of the world, and the overthrow of Aristotelian tradition, are mainly due. His influence, however, has been exaggerated. I am not going to enter into a discussion of the *Novum Organon*, and the mechanical methods which he propounded as certain to evolve truth if patiently pursued; for this is what he thought he was doing—giving to the world an infallible recipe for discovering truth, with which any ordinarily industrious man could make discoveries by means of collection and discrimination of instances. You will take my statement for what it is worth, but I assert this: that many of the methods which Bacon lays down are not those which the experience of mankind has found to be serviceable; nor are they such as a scientific man would have thought of devising.

"True it is that a real love and faculty for science are born in a man, and that to the man of scientific capacity rules of procedure are unnecessary; his own intuition is sufficient, or he has mistaken his vocation,—but that is not my point. It is not that Bacon's methods are useless because the best men do not need them; if they had been founded on a careful study of the methods actually employed, though it might be unconsciously employed, by scientific men—as the methods of induction, stated long after by John Stuart Mill, were founded—then, no doubt, their statement would have been a valuable service and a great thing to accomplish. But they were not this. They are the ideas of a brilliant man of letters, writing in an age when scientific research was almost unknown, about a subject in which he was an amateur. I confess I do not see how he, or John Stuart Mill, or any one else, writing in that age, could have formulated the true rules of philosophizing; because the materials and information were scarcely to hand. Science and its methods were only beginning to grow. No doubt it was a brilliant attempt. No doubt also there are many good and true points in the statement, especially in his insistence on the attitude of free and open candour with which the investigation of nature should be approached. No doubt there was much beauty in his allegories of the errors into which men were apt to fall—the *idola* of the market-place, of the tribe, of the theatre, and of the den; but all this is literature, and on the solid progress of science may be said to have had little or no effect. Descartes's *Discourse on Method* was a much more solid production."

"You will understand that I speak of Bacon purely as a scientific man. As a man of letters, as a lawyer, a man of the world, and a statesman, he is beyond any criticism of mine. I speak only of the purely scientific aspect of the *Novum Organon. The Essays* and *The Advancement of Learning* are masterly productions; and as a literary man he takes high rank."

Note also in this connection the opinion of Prof. Draper, quoted by Lodge, page 143, from the former's 'History of Civilization in Europe,' vol. ii. page 259.

"The more closely we examine the writings of

Lord Bacon, the more unworthy does he seem to have been of the great reputation which has been awarded to him. The popular delusion to which he owes so much originated at a time when the history of science was unknown. They who first brought him into notice knew nothing of the old school of Alexandria. This boasted founder of a new philosophy could not comprehend, and would not accept, the greatest of all scientific doctrines when it was plainly set before his eyes.

"It has been represented that the invention of the true method of physical science was an amusement of Bacon's hours of relaxation from the more laborious studies of law, and duties of a court.

"His chief admirers have been persons of a literary turn, who have an idea that scientific discoveries are accomplished by a mechanico-mental operation. Bacon never produced any great practical result himself, no great physicist has ever made any use of his method. He has had the same to do with the development of modern science that the inventor of the orrery has had to do with the discovery of the mechanism of the world. Of all the important physical discoveries, there is not one which shows that its author made it by the Baconian instrument.

"Newton never seems to have been aware that he was under any obligation to Bacon. Archimedes, and the Alexandrians, and the Arabians, and Leonardo da Vinci did very well before he was born; the discovery of America by Columbus and the circumnavigation by Magellan can hardly be attributed to him, yet they were the consequences of a truly philosophical reasoning. But the investigation of Nature is an affair of genius, not of rules. No man can invent an *organon* for writing tragedies and epic poems. Bacon's system is, in its own terms, an idol of the theatre. It would scarcely guide a man to a solution of the riddle of Ælia Lælia Crispis, or to that of the charade of Sir Hilary.

"Few scientific pretenders have made more mistakes than Lord Bacon. He rejected the Copernican system, and spoke insolently of its great author; he undertook to criticise adversely Gilbert's treatise *De Magnete;* he was occupied in the condemnation of any investigation of final causes, while Harvey was deducing the circulation of the blood from Aquapendente's discovery of the valves in the veins; he was doubtful whether instruments were of any advantage, while Galileo was investigating the heavens with the telescope. Ignorant himself of every branch of mathematics, he presumed that they were useless in science but a few years before Newton achieved by their aid his immortal discoveries."

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Electricity at the Paris Exposition
OF 1889.

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